Defence Research and Development Canada | Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Human Factors Issues for Controlling Uninhabited Aerial Vehicles:

Preliminary Findings in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System Project

G. Robert Arrabito
Geoffrey Ho
Annie Lambert
Mark Rutley
Jocelyn Keillor
Allison Chiu
Heidi Au
Ming Hou

Defence R&D Canada
Technical Report
DRDC Toronto TR 2009-043
November 2010

Canada

Human Factors Issues for Controlling Uninhabited Aerial Vehicles

Preliminary Findings in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System Project

G. Robert Arrabito
Geoffrey Ho
Annie Lambert
Mark Rutley
Jocelyn Keillor
Allison Chiu
Heidi Au
Ming Hou

Defence R&D Canada – Toronto

Technical Report

DRDC Toronto TR 2009-043

November 2010

Principal Author

Original signed by G. Robert Arrabito

G. Robert Arrabito

Defence Scientist

Approved by

Original signed by Linda Bossi

Linda Bossi

Head, Human Systems Integration Section

Approved for release by

Original signed by K.C. Wulterkens

K. C. Wulterkens

for Chair, Knowledge and Information Management Committee

Abstract

The Directorate Technical Airworthiness and Engineering Support 6 tasked Defence Research and Development Canada (DRDC) – Toronto to provide a preliminary summary of human factors issues related to the control of uninhabited aerial vehicles (UAVs) in support of the Canadian Forces (CF) Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) Project. This was carried out by performing a literature review and consulting with subject matter experts at Creech United States Air Force (USAF) Base (Indian Springs, NV) and Kirtland USAF Base (Albuquerque, NM). The human factors identified were grouped into three categories: organizational influences, operator influences, and human-system integration issues. The key findings were: (1) human factors play a major role in UAV mishaps; (2) operator vigilance is required in automated UAV control; (3) recent increases in long-endurance UAV operations have necessitated shift work schedules to man the Ground Control Station (GCS) around-the-clock causing UAV operators to experience fatigue leading to serious implications on health and performance; (4) a GCS that supports a multimodal display (i.e., the presentation of visual, auditory, and tactile information) can enhance operator performance; and, (5) prior pilot experience may not be a mandatory criterion for selecting personnel for operating a medium-altitude, long-endurance (MALE) UAV. This report concludes by proposing short- and long-term recommendations for defining future requirements in support of the JUSTAS project.

Résumé

La Direction - Navigabilité aérienne et soutien technique a chargé Recherche et développement pour la Défense Canada (RDDC) – Toronto de présenter un sommaire préliminaire au sujet de l’incidence des facteurs humains sur le contrôle des véhicules aériens télépilotés (UAV) à l’appui du projet de Système interarmées d’acquisition d’objectif au moyen de véhicules aériens télépilotés de surveillance (JUSTAS). À cette fin, une analyse documentaire a été effectuée et des experts dans le domaine œuvrant dans les bases aériennes (AFB) de Creech et de Kirtland aux États-Unis ont été consultés. Les facteurs humains ainsi identifiés ont été groupés en trois catégories : les influences organisationnelles, les influences de l’opérateur et les interactions entre la personne et le système. Plusieurs éléments principaux sont ressortis de cette étude. (1) Les facteurs humains sont les principaux éléments contributifs aux accidents d’UAV. (2) L’opérateur qui contrôle l’UAV doit rester vigilant. (3) En raison de l’augmentation de l’utilisation d’UAV à grande autonomie, un horaire de quarts de travail a été instauré afin qu’un opérateur soit en fonction en tout temps au poste de contrôle au sol. La fatigue qu’engendre ce rythme de travail a de graves incidences sur la santé et le rendement des opérateurs. (4) Un poste de contrôle au sol équipé d’affichages multimodaux (c’est-à-dire avec présentation visuelle, auditive et tactile de l’information) peut considérablement améliorer le rendement de l’opérateur. (5) L’expérience préalable de pilote ne devrait pas être un critère de sélection obligatoire pour les candidats au poste d’opérateur d’UAV moyenne altitude et grande autonomie (MALE). En conclusion, le présent rapport propose plusieurs recommandations, pour le court terme et le long terme, visant à cerner les exigences futures à l’appui du projet JUSTAS.

This page intentionally left blank.

Executive summary

Human Factors Issues for Controlling Uninhabited Aerial Vehicles: Preliminary Findings in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System Project

G. Robert Arrabito; DRDC Toronto TR 2009-043; Defence R&D Canada – Toronto; January 2010.

Background: Uninhabited aerial vehicles (UAVs) are critical to the Canadian Forces (CF) for conducting domestic and international command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR). To improve CF UAV capability, the CF Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project was recently launched to define the statement of requirements for the acquisition of a medium-altitude, long-endurance (MALE) UAV. In support of the JUSTAS project, the Directorate Technical Airworthiness and Engineering Support 6 tasked Defence Research and Development Canada (DRDC) – Toronto to provide a preliminary summary of human factors issues related to controlling UAVs.

Results: The information in this report was acquired from the open literature. Also, two CF Air Accident Investigators from the Canadian Forces Environmental Medicine Establishment (CFEME) visited the Creech United States Air Force (USAF) Base (Indian Springs, NV) and the Kirtland USAF Base (Albuquerque, NM) to consult with MALE UAV operators. The result of this investigation showed that human factors play a major role in UAV accidents and incidents. Different human factors issues arise with various methods of operating and controlling UAVs. For UAVs that are manually flown (e.g., manual take-off and landing), the human factors issues are primarily related to a loss of sensory cues that are valuable for flight control, delays in UAV control inherent in the data link, and difficulty in scanning the visual environment surrounding the UAV. In contrast, for UAVs that are highly automated (e.g., automated take-off and landing, and pre-programmed flight), the human factors issues are primarily related to problems in operator supervisory control such as maintaining vigilance. Many of these human factors issues can benefit from a ground control station (GCS) interface that supports a multimodal display (i.e., the presentation of visual, auditory, and tactile information). Another human factors issue is UAV operator fatigue caused by shift work schedules implemented to man the Ground Control Station (GCS) around-the-clock due to recent increases in long-endurance UAV operations. Fatigue has serious implications for UAV pilots such as reduced decision making capability, reduced memory performance, and decreased ability to focus during vigilance tasks. Finally, given that UAVs are remotely operated, the skills and knowledge required to operate a MALE UAV must be identified to develop a CF military occupation classification.

Significance: This report provides a preliminary review of human factors issues related to the control of UAVs pertaining to organizational influences, operator influences, and human-system

integration issues. This report will serve as an introductory document for JUSTAS to enhance operator performance for ensuring CF operational effectiveness.

Future plans: This report provides short- and long-term recommendations for defining future requirements in support of the JUSTAS project. Short-term recommendations are: (1) perform a cognitive task analysis (CTA) on existing CF CU-170 Heron UAV operators to identify skills and knowledge in order to specify the cognitive processes to operate a MALE UAV; and (2) perform a CF Human Factors Analysis and Classification System of all MALE UAV mishap data from original accident reports (if possible) to classify personnel cause factors in order to minimize UAV mishaps. Long-term recommendations are: (1) perform research to develop a systematic methodology for selecting UAV operators in the CF; (2) develop and host an international human factors UAV symposium to discuss personnel cause factors; and (3) perform research to mitigate the vigilance decrement and operator fatigue associated with shift work.

Sommaire

Incidence des facteurs humains sur le pilotage des véhicules aériens télépilotés : Constatations préliminaires à l'appui du projet de Système interarmées d'acquisition d'objectif au moyen de véhicules aériens télépilotés de surveillance des Forces canadiennes

G. Robert Arrabito; DRDC Toronto TR 2009-043; R & D pour la défense Canada – Toronto; Décembre 2010.

Introduction : Les Forces canadiennes comptent beaucoup sur les véhicules aériens télépilotés (UAV) pour remplir leurs missions nationales et internationales de C4ISR (commandement, contrôle, communications, informatique, renseignement, surveillance et reconnaissance). Le projet de Système interarmées d'acquisition d'objectif au moyen de véhicules aériens télépilotés de surveillance (JUSTAS) a récemment été lancé afin de doter les Forces canadiennes d'un plus grand nombre d'UAV. Ce projet vise à définir les exigences en vue de l'acquisition d'un UAV volant à moyenne altitude et d'une grande autonomie (MALE). À l'appui du projet JUSTAS, la Direction - Navigabilité aérienne et soutien technique a chargé Recherche et développement pour la défense Canada (RDDC) – Toronto de présenter un sommaire préliminaire sur l'incidence des facteurs humains sur le pilotage des UAV.

Résultats : L'information contenue dans le présent rapport provient d'une analyse de documents non classifiés et des observations de deux enquêteurs sur les accidents aériens du Centre de médecine environnementale des Forces canadiennes (CMEFC) qui ont visité les bases aériennes (AFB) de Creech et de Kirtland aux États-Unis afin d'y rencontrer les opérateurs des UAV MALE. Cette enquête a révélé que les facteurs humains jouent un rôle prépondérant dans les incidents et les accidents d'UAV. Les différentes méthodes d'exploitation et de pilotage des UAV génèrent différents problèmes associés aux facteurs humains. Lorsque les UAV sont télépilotés manuellement (p. ex. au décollage et à l'atterrissage), les problèmes associés aux facteurs humains sont principalement reliées aux pertes de données sensorielles essentielles à la maîtrise du vol, au décalage entre la sollicitation des commandes par l'opérateur et la réponse de l'UAV inhérent à la transmission des données, et aux difficultés que présente le balayage visuel de l'environnement de l'UAV. Par contre, en ce qui concerne les UAV hautement automatisés (p. ex. atterrissage et décollage automatisés, vol préprogrammé), les problèmes associés aux facteurs humains sont surtout reliés aux problèmes de surveillance du vol par l'opérateur, notamment au maintien de la vigilance. Un poste de contrôle au sol doté d'interface UAV à affichages multimodaux (avec présentation visuelle, auditive et tactile de l'information) pourrait considérablement atténuer les problèmes associés aux facteurs humains. Un autre facteur est la fatigue de l'opérateur causée par les quarts de travail instaurés afin d'assurer la permanence au poste, une mesure rendue nécessaire par le nombre accru d'opérations UAV de grande autonomie. En effet, la fatigue a de graves conséquences pour les pilotes d'UAV puisqu'elle affaiblit leur capacité décisionnelle, leur capacité de concentration sur les tâches exigeant de la vigilance et elle nuit à leur performance mnésique (Thompson et coll., 2006). Enfin, les UAV devant être télépilotés, il est important de cerner les compétences et les connaissances que

nécessite l'exploitation d'un UAV MALE afin de définir un groupe professionnel militaire spécifique à ces opérateurs.

Portée : Le présent rapport porte sur un examen préliminaire des problèmes liés aux facteurs humains associés au pilotage de l'UAV, notamment en ce qui concerne les influences organisationnelles, les influences qui s'exercent sur l'opérateur et les interactions entre la personne et le système. Le présent rapport servira d'introduction pour le projet JUSTAS afin d'améliorer le rendement de l'opérateur et ainsi assurer l'efficacité opérationnelle des FC.

Recherches futures : Le présent rapport contient des recommandations à mettre en œuvre à court et long termes visant à cerner les besoins à venir du projet JUSTAS. Voici les recommandations à mettre en œuvre à court terme : (1) procéder à une analyse cognitive des tâches effectuées par les opérateurs actuels des UAV CU170 Heron des FC afin de cerner les compétences et les connaissances qu'exige leur poste et ainsi définir les processus cognitifs applicables à l'exploitation d'un UAV MALE; (2) en appliquant le système d'analyse et de classification des facteurs humains des FC, procéder à une analyse de toutes les données sur les accidents UAV MALE extraites des rapports d'accidents originaux (si possible) afin de classer les facteurs contributifs associés au personnel dans le but de minimiser ces accidents. Les recommandations à mettre en œuvre à long terme sont : (1) effectuer une recherche afin de mettre au point une méthodologie systématique applicable à la sélection des opérateurs d'UAV dans les FC; (2) organiser et accueillir un symposium international sur les facteurs humains associés à l'exploitation des UAV afin de discuter des facteurs contributifs liés au personnel; (3) effectuer une recherche dans le but d'atténuer la baisse de vigilance et la fatigue de l'opérateur associées au travail par quarts.

Table of contents

List of figures

List of tables

Acknowledgements

We thank Maj (Ret’d) Linda Bossi, Dr. Philip Farrell, and LCol Charles Ness for helpful comments and suggestions on an earlier draft of this report. We thank April Lee, Andrew Sun, Michelle Sun, and Elizabeth Yeung for providing technical assistance

This page intentionally left blank.

1 Introduction

1.1 Background

Uninhabited aerial vehicles (UAVs) are remotely controlled aircraft used for a wide variety of civilian and military applications including law enforcement, firefighting, and meteorological data collection (van Blyenburgh, 1999). Various payloads are carried on UAVs that include cameras, sensors, communications equipment, and munitions. In the Canadian Forces (CF), UAVs are critical to help meet the CF's defence and security commitments for conducting domestic and international command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR). Since 2003, the CF have operated the CU-161 Sperwer tactical UAV in their ongoing mission in Afghanistan, but upgraded to the CU-170 Heron UAV in late 2009. The Heron is a medium-altitude, long-endurance (MALE) UAV that has a greater range and more sophisticated functions than the Sperwer. The CF is currently leasing the Israeli built Heron UAVs from MacDonald, Dettwiler and Associates (MDA) of Richmond, British Columbia. To enhance CF C4ISR capability, the CF Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project was recently launched to define the statement of requirements for the acquisition of a MALE UAV. In support of the JUSTAS project, human factors issues related to the control of UAVs must be considered to reduce UAV mishaps given the higher mishap rates for UAVs relative to manned aircrafts (Williams, 2004). The goal of human factors is to accommodate the limits of human performance and exploit the advantages of the human operator by applying knowledge of human capabilities and limitations in the design of systems (Wickens & Hollands, 2000).

The Directorate Technical Airworthiness and Engineering Support 6 tasked Defence Research and Development Canada (DRDC) – Toronto in January 2009 to provide a preliminary summary of human factors issues in the control of UAVs, and to make recommendations for defining future requirements in support of the JUSTAS project. DRDC Toronto has been actively involved in investigating human factors issues related to the control of UAVs. This has been directed at producing knowledge, tools and simulators that can be used by the CF to improve both acquisition and training activities. As of April 1, 2009, DRDC Toronto was funded for an applied research program (ARP), under Partner Group 13QH (Command), to investigate the efficacy of a multimodal display (i.e., the presentation of visual, auditory, and tactile information) in a UAV ground-control station (GCS). This ARP will develop concepts of operations to best integrate information from multiple sensory inputs to enhance situation awareness (SA). A definition of SA from the literature, which may be adopted for operations, is the "perception of the elements in the environment within a volume of space and time, the comprehension of their meaning and the projection of their status in the near future" (Endsley, 1988, p. 97). This ARP will evaluate the effectiveness of interventions in a GCS simulator that will help address barriers to SA in a visually dominant GCS interface. The results of this ARP will help define the statement of requirements of a MALE UAV for the JUSTAS project.

1.2 Purpose and Scope

The purpose and scope of this report is to present human factors issues related to the control of UAVs that can help define the statement of requirements of a MALE UAV in support of the CF JUSTAS project. Information on human factors issues related to controlling UAVs was acquired from the open literature, complemented by anecdotal evidence gathered in consultation with operators of the Predator UAV (a MALE UAV) by two Air Accident Investigators from Canadian Forces Environmental Medicine Establishment (CFEME) during a site visit to Creech United States Air Force (USAF) Base (Indian Springs, NV) and Kirtland USAF Base (Albuquerque, NM). The trip report is presented in **Annex A**. Mock-up figures of the MQ-1 Predator UAV are presented in **Annex B**.

Section **2** discusses UAV mishaps attributed to human error. Specifically, examples of USAF mishaps for the Predator UAV are provided. Subsequently, UAV mishaps attributed to human error for the CF and USAF are tabulated. The CF Human Factors Analysis and Classification System (HFACS) (Department of National Defence, 2007) is applied to classify personnel cause factors of UAV accidents and incidents in the CF and USAF (**Annex C**). This is followed by preliminary conclusions of the mishap data from these two military organizations. Section **3** provides a preliminary review of human factors issues related to the control of UAVs pertaining to organizational influences, operator influences, and human-system integration (HSI) issues. Conclusions are presented in Section **4**. Some short- and long-term recommendations for defining future requirements in support of the JUSTAS project are presented in Section **5**. **Annex D** describes a site visit to observe the Heron UAV at Canadian Forces Base (CFB) Suffield/ MDA in Alberta by a DRDC Toronto Defence Scientist.

2 Personnel Cause Factors in UAV Mishaps

The use of UAVs in United States (US) military operations is expanding rapidly and this trend will likely continue given increases in U.S. funding for UAV development from $3 billion in the 1990s to over $12 billion for 2004-2009 (Nullmeyer, Herz, Montijo, & Leonik, 2007). For example, the Predator is used by the USAF to provide reconnaissance imagery and close-air support to ground commanders in Iraq and Afghanistan, and the CF uses the CU-170 Heron (**Annex D**) in Afghanistan. While there is considerable demand for UAV support, the rapid rise in UAV employment has been accompanied by high mishap rates.

As early as 2001, the UAV mishap rate was considered significantly higher than that of manned aircraft (Williams, 2004). Several investigators identified human factors issues in operator control of UAVs (Herz, 2008; Manning, Rash, LeDuc, Noback, & McKeon, 2004; McCarley & Wickens, 2005; Tvaryanas, Thompson, and Constable, 2005; Williams, 2004). Tvaryanas et al. (2005) found that a relatively high frequency of UAV mishaps that occurred over 10 years in the US Army, Air Force, and Navy/Marines was due to human factors issues that included problems with high workload, attention, and crew coordination and communication. Manning et al. (2004) reported that human error was cited in approximately one third of all U.S. Army UAV accidents for the period covering fiscal years 1995-2003. Williams (2004) examined causal factors in US Army Predator UAV accident reports and found that human factors-related problems encompassed a higher percentage (67%) of accident cause factors than aircraft-related mechanical problems. Navy Pioneer UAV human factors issues were cited for aircrew coordination, take-off, landing, and weather.

To help understand the extent of human factors-related issues in UAV mishaps, the remainder of this section focuses on personnel cause factors in UAV mishaps. Section **2.1** provides examples of human error cited in USAF Predator UAV mishaps as reported by Herz (2008). The CF Human Factors Analysis and Classification System (HFACS) (Department of National Defence, 2007) was applied to classify personnel cause factors of UAV mishaps in the CF and USAF (Annex C), which is discussed in Section **2.2**. Section **2.3** draws preliminary conclusions to the mishap data from the CF and USAF.

2.1 USAF Predator UAV Mishaps reported by Herz (2008)

This section focuses on Predator mishaps. A detailed analysis of USAF Predator UAV Mishaps is reported by Herz (2008). Research scientist LCol Robert P. Herz at the USAF Research Laboratory (Mesa, AZ) recently completed a doctoral dissertation that assessed the influence of human factors and potential impact of experience factors (i.e., total flight hours, total Predator-specific flight hours, sortie frequency) on USAF Predator mishaps as measured by unsafe acts and the frequency and cost of mishaps (Herz, 2008). He retrieved the Predator mishap data from the Accident Investigation Board (AIB) summary reports, Safety investigation summaries, the human factors database from the USAF Safety Center (Albuquerque, NM), and mishap investigation reports.

The Predator was introduced into the operational USAF inventory in fiscal year (FY) 1997. Based on rapidly increasing Predator UAV operations, the period of 1997-2007 saw a dramatic increase in Predator flying hours as shown in *Figure 2-1*. Specifically, the number of hours rose from less than 3000 hours in 1997 to just under 80,000 hours in 2007. During the period of FY 1996 to the end of FY 2006, there were 64 Predator mishaps: 27 Class A (greater than a $1 million in damage or a fatality), 3 Class B (greater than a $200,000 in damage), and 34 Class C (greater than $20,000 in damage mishaps). The number of mishaps per 100,000 flying hours for the period 1999-2007 is shown in *Figure 2-2*. To put these mishap rates into perspective, Predator UAV mishaps represented 20% of all Air Force Class A aviation mishaps for fiscal years 2004-2006. Although Predator mishap rates decreased over the years, the large increase in flying hours for fiscal years 2004-2006 led to an overall rise in the number of mishaps. As of 2007, the mishap rate was approximately 5 mishaps per 100,000 flying hours. Despite these improvements, the Air Force Safety Center's loss acceptability standards required the USAF to make every effort to conform to the loss rate of no more than one mishap per 100,000 flying hours.

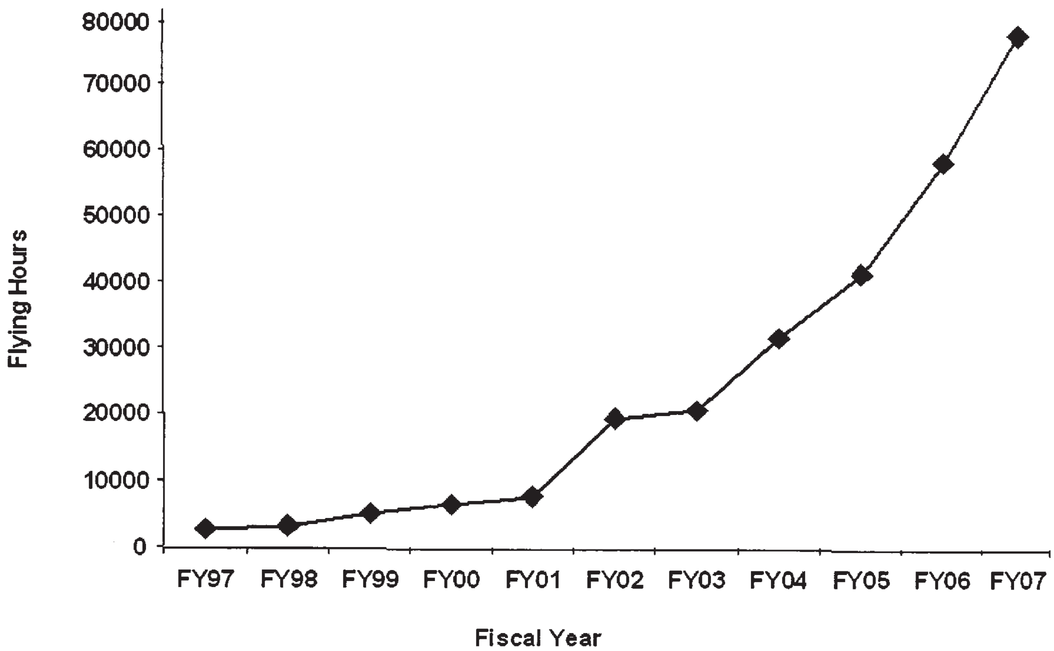


Figure 2-1: Predator flying hours, FY 1997 - FY 2007 (Herz, 2008, p. 89).

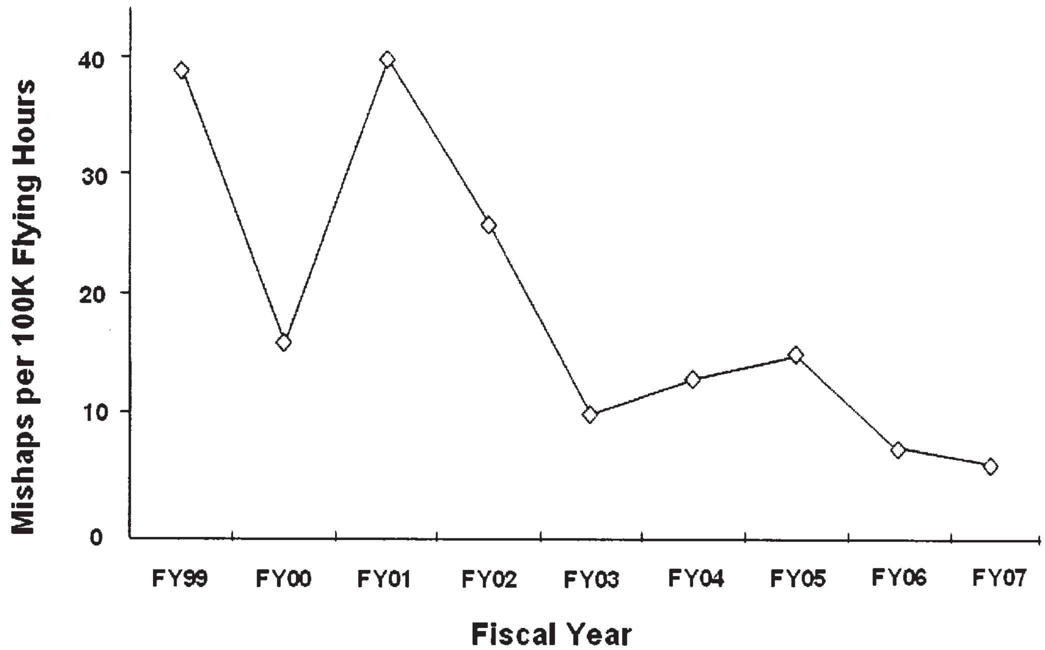


Figure 2-2: Predator mishap rates, FY 1999 - FY 2007 (Herz, 2008, p. 91).

Herz (2008) reviewed mishap reports to identify the mission phases in which Class A, B, and C mishaps occurred. The phases of flight that were given specific attention were taxi, take-off, enroute, and landing. The contributing factors for mishaps in each of these phases were categorized into logistics, maintenance and operations. *Figure 2-3* shows Class A Predator mishaps between 1997-2007 according to phase of flight. The Predator mission may last 20 hours or more. The largest proportion of Class A mishaps occurred during the enroute phase, which accounts for the largest proportion of hours flown. *Figure 2-4* shows Class B and C Predator mishaps between 1997-2007 according to phase of flight. The largest proportion of Class B and C mishaps occurred during the landing phase. Although the taxi and takeoff phases may last only a few minutes, Herz notes that the Predator UAV is “challenging at best to land and has a tight envelope of operational tolerance to produce a smooth landing” (Herz, 2008, p. 98). These qualities, hampered by slow bandwidth and response times of the remotely controlled interface, make it difficult to recover from a misdirected landing.

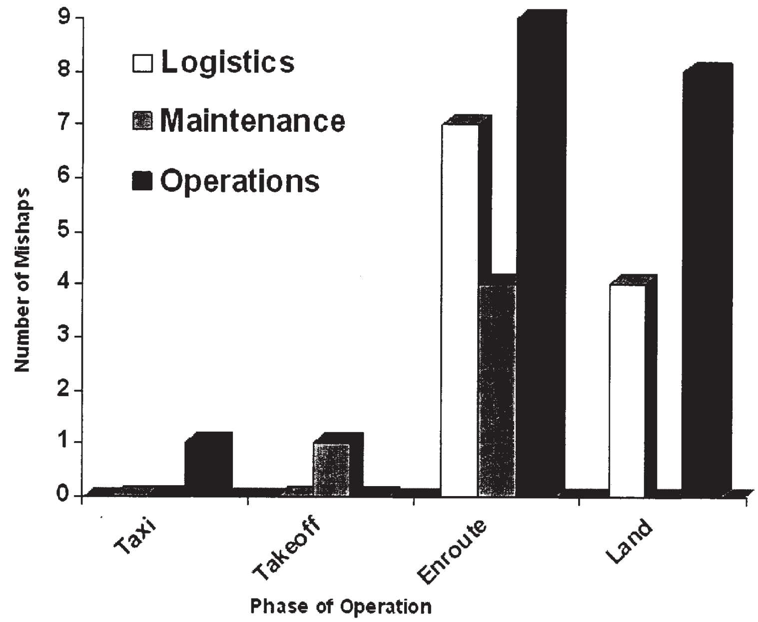


Figure 2-3: Class A Predator mishaps – phase of flight (Herz, 2008, p. 99).

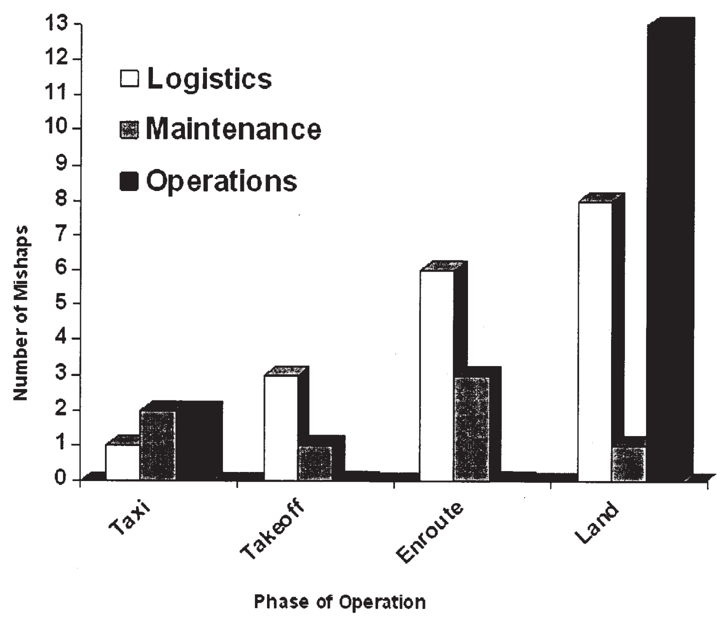


Figure 2-4: Class B & C Predator mishaps – phase of flight (Herz, 2008, p. 100).

Of the 64 Class A, B, and C mishaps in the period 1997-2007, Herz (2008) found that 40 (62.5%) cited human error as a major or contributing factor. The mishap elements fell into eight general bins including interface, decisions, skills/knowledge, SA, teamwork, documentation, mission preparation, and organization. To help identify trends in Predator UAV Class A mishaps, he divided the ten year period into two eras: Era 1 covering fiscal years 1997-2003, and Era 2 covering fiscal years 2004-2006. He explains that the break between first and second eras coincided with the change in training philosophy adopted by the USAF at the end of 2003 where on-the-job training for Predator pilots largely comprised of over-the-shoulder supervision in the GCS. Subsequently, simulators played an increased role in student training because there was a rapid acceleration of additional operational flying hours levied on Predator pilots that limited one-on-one training by instructors to students.

Mishap reports from Era 1 typically cited mechanical problems and operator station design issues. *Figure 2-5* shows the frequency that each human factors attribute was cited as a major or contributing factor for Class A mishaps for Era 1. *Table 2-1* provides examples of each human factors attribute cited for Class A mishaps.

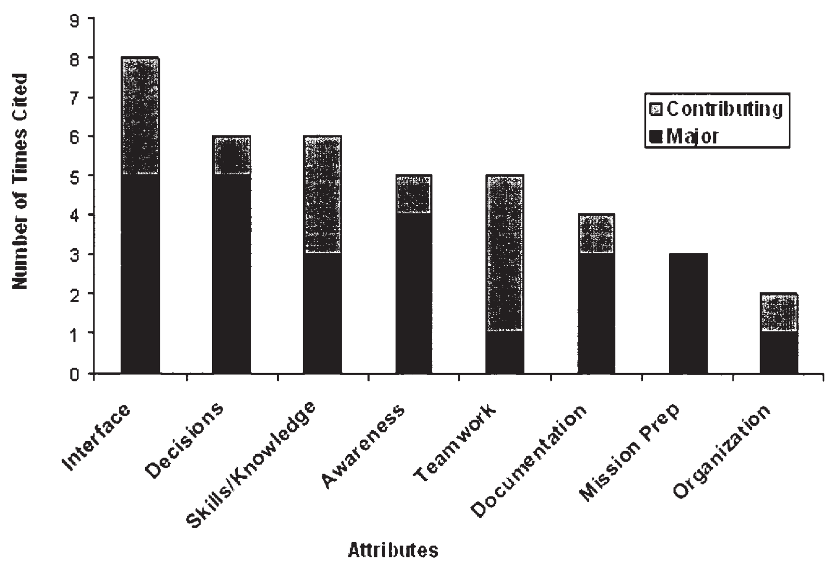


Figure 2-5: Human factors attributes in Class A Predator mishaps, 1997-2003 (Herz, 2008, p. 103).

Mishap reports from Era 2 cited causal human error factors for 80% of the mishaps. *Figure 2-6* shows the frequency that each human factors attribute was cited as a major or contributing factor for Class A mishaps for Era 2. *Table 2-1* provides examples of each human factors attribute cited for Class A mishaps. Mechanical problems were less frequently cited in Era 2; rather, skills/knowledge, SA, and teamwork factors were cited more frequently.

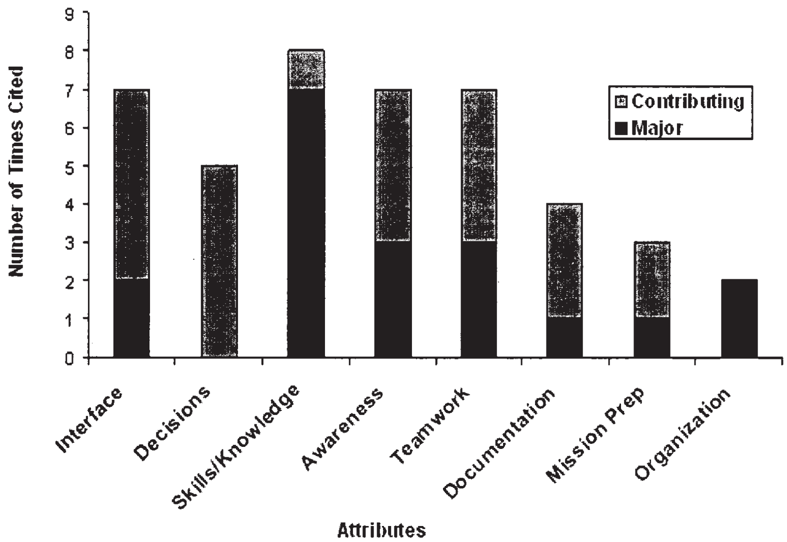


Figure 2-6: Human factors attributes in Class A Predator mishaps, 2004-2006 (Herz, 2008, p. 104).

Unlike Class A mishaps, Class B and C mishaps were not divided into two eras since no significant differences were found between the two eras. *Figure 2-7* shows the frequency that each human factors attribute was cited as a major or contributing factor for Class B and C mishaps for 1997-2006. *Table 2-1* provides examples of human factors attributes cited for Class B and C mishaps.

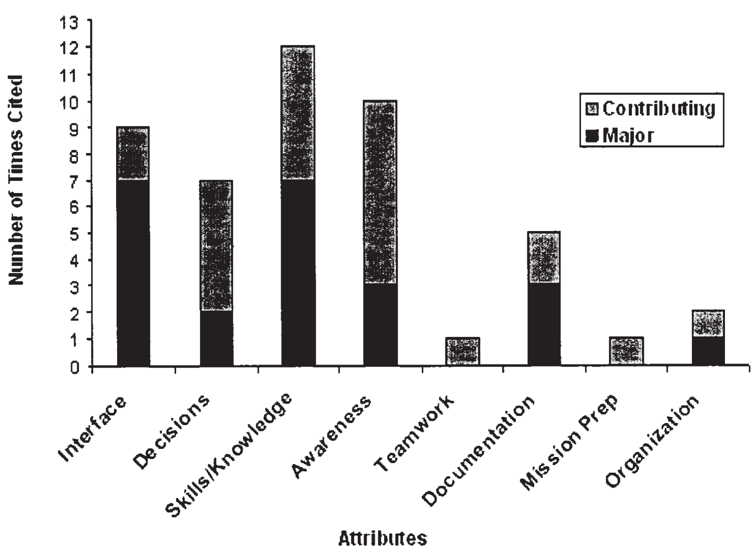


Figure 2-7: Human factors attributes in Class B & C Predator mishaps, 1997-2006 (Herz, 2008, p. 106).

Table 2-1: Human factors (HF) attributes cited in Predator UAV mishaps (adapted from Herz, 2008)

HF Attribute	Elements Contained within Attributes	Class A Element	Class B & C Element
Interface	Functional design of system, program logic, functional deficiency, instrumentation location, confidence in equipment, operability of controls and switches, switch locations	Poor system design, switchology	Poor human-interface / lack of feedback
Decision-making	Checklist errors, task misprioritization, delayed necessary actions, used wrong technique, inadvertent operations, course of action selected, risk assessment, peer or crew rule violation, and violation of flight discipline	Course of action selected / risk assessment	Poor risk assessment / judgement
Skills / Knowledge	Over or under control, lack of training for the task, limited total experience, systems knowledge, simulator training, event proficiency, technical procedural knowledge	Training for task, limited experience	No training for task, hastened training
Situation Awareness	Monitoring, channelized attention, inattention, confusion, misperception, distraction, spatial disorientation, vision restrictions due to weather	Channelized attention, inattention	Poor recognition of condition
Teamwork	Misinterpreted communications, crew coordination, rank imbalance or pilot in command and co-pilot syndrome, crew composition, intra-cockpit communication, crew leadership, subordinate style, interpersonal relationship, crew resource management	Instructor slow to react to student actions	Instructor-student communication
Documentation	Written procedures, employment guidance, logistics and maintenance procedures, aircraft operating limitations and parameters	Poor written procedures	Lack of critical performance data
Mission Preparation	Inadequate flight planning, insufficient flight briefing, eliminated or misinterpreted weather analysis, poor overall preparation	Eliminated or misinterpreted weather analysis, unusual operations planning (e.g., a)	No dynamic workarounds, forecasting of planned route obstacles

		inadequate flight planning, b) insufficient flight briefing, and c) poor overall preparation)	
Organization	Discipline enforcement, crew coordination training, inadequate supervision, inadequate ground or flight training, program risk assessment, government oversight, and supervision availability	Not providing disciplined task training	Inappropriate waivers, no test phase

The following is an elaboration of each human factors attribute in *Table 2-1* as related by Herz (2008):

- Interface: One example of a Predator UAV interface issue is the insufficient field of view which it provides, which leaves the pilot without visual reference of the runway during landings. The interface limitations, combined with a lack of haptic feedback, can lead pilots to believe that they have landed successfully, while in reality, still 10 feet above surface. Subsequently, the aircraft undergoes a 10-foot nose dive and a runway impact that causes damage to the $1M sensor ball on the underside of the UAV, resulting in a Class A mishap (Herz, 2008, p. 109).

- Decision-making: Multiple decision-making errors can compound resulting in a catastrophic mishap. For example, poor mission preparation and further misjudgements, such as not running the Airframe Icing checklist, contributed to a UAV mishap (Herz, 2008, p. 110). As well, factors such as peer pressure and fear of ridicule from a botched landing can influence a pilot's decision making. For example, in an effort to try and save a poor landing, one pilot decided to land outside of parameters rather than follow regulations and go-around, leading to a $88,000 damage to the UAV (Herz, 2008, p. 110).

- Skills/Knowledge: Skills/knowledge factors are the greatest contributor to Predator mishaps (Herz, 2008, p. 110). Inadequate classroom and simulator training, and insufficient outside aircraft flying experience can lead to skill/knowledge gaps resulting in Predator mishaps. For example, insufficient training in theatre where operators are faced with more advanced satellite communication link technologies, unfamiliar conditions, unfamiliar checklists, and insufficient supervision have led to UAV mishaps (Herz 2008, p. 111).

- Awareness: Poor situation awareness can lead to poor recognition of conditions until it is too late to respond effectively (Herz, 2008, p. 105). Lack of situation awareness can manifest from insufficient information provided by the interface, depriving pilots of critical cues for operating the UAV (e.g. limited field of view). Channelized attention can also distract a pilot from critical warnings/issues. For example, in becoming too focused on a faulty airspeed indicator, one pilot failed to notice a frozen pitot static port. This caused the autopilot to put the aircraft into a dive, from which the pilot was not able to recover the UAV (Herz, 2008, p. 111).

- Teamwork: Some Predator UAV missions require 55+ personnel, with 3-4 sets of crew members operating a single UAV over a mission (Herz, 2008, p. 113). Miscommunication, poor handoff procedures or differences in personal techniques may lead to human errors in piloting the UAV, and subsequently, a mishap. Role confusion, such as between an instructor and a student pilot, may also lead to a mishap. For example, when there is uncertainty about who controls the aircraft when troubleshooting an emergency procedure, a mishap could occur (Herz, 2008, p. 104).

- Documentation: Since the Predator UAV was hastily accelerated into operational utility status, several components (e.g., detailed alarms, warnings, caution and standard operating procedures and parameters of how a particular airframe should be flown) were not included in the documentation. For example, critical instructions on how to perform a normal landing were not documented. Consequently, pilots were left without key information and had to rely on personal experience and experimentation, making them vulnerable to mishaps (Herz, 2008, p. 113-114).

- Mission Preparation: Poor planning on the pilot's part can lead to UAV flight in unfavourable or dangerous conditions. For example, while the autopilot was engaged, the mishap aircraft was led into near freezing levels and areas of rain and turbulence, which resulted in a $1.5 million mishap. Instead, the pilot should have taken advantage of numerous resources to plan the flight around the hazardous weather (Herz, 2008, p. 114).

- Organization: Operational issues such as insufficient operational risk management can lead to UAV mishaps. For example, inadequate support measures and communication with flight commanders and instructors left one Predator pilot without aid. After performing three missed attempts at a safe landing, the distressed pilot elected to force the aircraft down for a landing. This organizational blunder resulted in $34,000 damage to the UAV (Herz, 2008, p. 115).

2.2 CF HFACS Applied to CF and USAF UAV Mishaps

Given the high UAV mishap rates, multiple reviews of UAV mishaps were carried out during the past several years (e.g., Herz, 2008; Manning et al., 2004; Tvaryanas et al., 2005; Williams, 2004). Herz (2008) noted that even within common UAV platforms, different analysts attributed these mishaps to differing causes. Manning et al. (2004) found that a substantial amount of data was missing from UAV mishap reports. There was no consistent nomenclature used in the identification of UAV types involved in the accidents. Identification ranged from precise models (e.g., RQ-5 Hunter and RQ-7 Shadow) to general terms such as "drone," "trainer," and "UAV". Operator information such as gender, age, and number of hours on duty was also absent in at least 30% of the reports (Manning et al., 2004). This makes it difficult to determine which human factors problems are common in military organizations and likely inherent to all UAV operations and UAV type. To the authors' knowledge, none of the investigations between the CF and the US military services utilize a similar human factors taxonomy that could allow the direct comparison of findings.

In an initial attempt to draw preliminary conclusions between mishap data sets from the CF and USAF, the CF HFACS (Department of National Defence, 2007) was utilized. The CF HFACS is a system of classification of human error in aviation organizations. This publication defines an unsafe act as the initial point of departure from safe operations leading to the mishap. In the CF HFACS classification system, every occurrence is preceded by one or more unsafe acts. These unsafe acts occur within an environment that is previously established by “preconditions”. There are three levels of pre-conditions in the CF HFACS system: preconditions to the unsafe act, supervisor, and organizational. For the purposes of this report, a mishap is defined as a damage or loss of an aircraft (e.g., Category A, B, or C accident) or events that are considered “near misses” (e.g., Category D or E event). Variations of CF HFACS have been used by other researchers to classify human error in aviation mishaps (e.g., Manning et al., 2004; Tvaryanas et al., 2005).

UAV mishap reports for the CF and USAF were acquired to illustrate the types of human factors problems identified in the control of UAVs. **Annex C** contains *Table C-1* and *Table C-2*, which are UAV mishap data that involved human error as a causal or contributing factor for the CF and USAF, respectively. The CF applies six cause factors to aviation occurrences. These cause factors are: personnel, materiel, environmental, operational, unidentified foreign object damage (FOD), and undetermined (Department of National Defence, 2007). Using the CF HFACS document, each mishap in **Annex C** was categorized into personnel and materiel cause factors. Personnel cause factors include acts of omission or commission by those responsible in any way for aircraft operation or maintenance, support to operations, and circumstances that contribute to a flight safety occurrence. Personnel cause factors consist of four levels: unsafe acts or conditions, preconditions for unsafe acts, supervision, and organizational influences. Materiel cause factors include failure of all aircraft components, support equipment and facilities used in the conduct and support of air operations that lead to a flight safety occurrence. Although most materiel failures may be traced ultimately to some human origin, personnel causes are assigned only when failures result from incorrect maintenance by CF or contracted parties or from incorrect operating procedures.

The CF HFACS was applied to each mishap report. These mishap reports are tabulated in **Annex C** separately for the CF (*Table C-1*) and the USAF (*Table C-2*). Each report contains information about the type of UAV involved in the mishap and a brief narrative description of the mishap. We searched each report to isolate the narrative that mentioned personnel cause factors and material cause factors. Once identified, the mishaps were categorized by mission phase: taxi (time between engine start to take-off and from touchdown to engine stop), take-off (from engine throttle up on runway to departure from circuit), climb (departure from circuit until level off altitude), cruise (maintaining altitude until beginning of descent), descent (departure from altitude until enter the circuit for landing), and landing (negotiate circuit until aircraft touches down).

2.2.1 CF UAV Mishaps

The mishap investigation reports for the CF were downloaded from the website of the Directorate of Flight Safety (http://www.airforce.forces.gc.ca/dfs-dsv/nr-sp/index-eng.asp?cat=262) on January 31, 2009. The mishaps occurred between November 21, 2003 and May 8, 2008. Of the 12 mishap reports, 7 (58.33%) include materiel cause factors and/or personnel cause factors. *Table C-1* presents these 7 CF Investigation Reports for the Sperwer UAV. Examples of human causal factors include lack of standardization of checklists and manuals, operator cognitive overload, and a lack of Human Performance in Military Aviation (HPMA) training for the UAV operational flight team. The most common theme of these mishaps is either missing procedures (e.g., mishaps 1, 4, and 7 in *Table C-1*) or a failure to follow existing procedures (e.g., mishap 3 in *Table C-1*).

2.2.2 USAF UAV Mishaps

The AIB reports were downloaded from the website of the USAF (http://usaf.aib.law.af.mil/) on January 31, 2009. The mishaps occurred between FY 2000 and FY 2008. Of the 38 mishap reports, 13 (34.21%) include materiel cause factors and/or personnel cause factors. *Table C-2* presents these 13 UAV mishaps from USAF for the Predator UAV. Examples of human causal factors include failure to execute checklist, incorrect actions due to lack of situation awareness, and inadequate supervision. The common themes of these mishaps are incorrect actions (e.g., mishaps 2, 3, 5, and 8 in *Table C-2*) and failure to execute checklist (e.g., mishaps 3, 6, and 13 in *Table C-2*).

2.2.3 Discussion of CF and USAF UAV Mishaps

As shown in the CF HFACS column of *Table C-1* and *Table C-2*, there appears to be a difference between the CF and the USAF mishap data. The majority of the USAF mishap data suggest that the greatest cause of human errors are skill-based that are due to either poor or inappropriate techniques (see mishap 11 of *Table C-2*), or the omission of proper techniques (see mishap 5 of *Table C-2*). Skill-based errors occur when well-trained, practiced, and automated routines or activities are performed incorrectly. In comparison, the majority of CF mishaps appear to have been caused by either improperly carrying out a task (e.g., a maintenance task) due to inadequate information or by improperly following checklists.

Our interpretation of the data in **Annex C** is contingent upon two factors that must be taken into consideration. First, the mishap reports in **Annex C** are drawn from the interpretations of those authoring the reports and not from raw event data. Second, there are differences between the Sperwer UAV and the Predator UAV. The Sperwer is a Tactical UAV (TUAV) and the Predator is a MALE UAV. Unlike a MALE UAV, a TUAV operates closer to the launch point, at lower altitudes and for shorter periods of time. As well, a MALE UAV often has strike capability. Additionally, the two UAVs take-off and land differently. Despite these two factors, both types of UAVs are operated from a GCS, both have man-in-the-loop interfaces, and both rely on a ground crew for certain aspects of their operation. Consequently, both UAVs have similar human performance criteria. Therefore, although the size, range and payload of these UAVs are different, they have similarities that allow for comparison of the human performance issues.

3 Human Factors Issues in UAV Operations

A MALE UAV (such as the Heron and the Predator) is remotely piloted from a GCS (Manning, et al., 2004). The functions of the GCS include: (1) receiving telemetry data from the UAV through a wireless modem; (2) processing these data; (3) displaying the UAV's status; and (4) supervising its navigation at way points. The GCS can be put on the ground or on another mobile carrier (e.g., ground vehicle, airborne platform, or marine vessel). The crew controls the UAV via a visual interface on the GCS. The GCS also allows the UAV crew to alter the UAVs mission and to communicate with air traffic control (ATC) and other team members. UAV operators must manage the competing goals and constraints of the aircraft, the mission, and the higher-level command and control (C2) structure (Linegang et al., 2006). Thus, the operating environment for UAVs shares similarities with other complex socio-technical environments (Rasmussen, 1998).

This section discusses some human factors issues in UAV operations. These are categorized as follows: organizational influences, operator influences, and human systems integration (HSI) issues. The information was acquired from the open literature. In addition, two CFEME Air Accident Investigators, on behalf of the JUSTAS project, visited USAF to gather preliminary information on MALE UAV combat operations. The USAF has been performing combat operations using the General Atomics built MQ-1 Predator UAV since 1995 and the larger MQ-9 Reaper UAV since 2007. Moreover, the USAF has armed their platforms, a capability which the CF will likely adopt in the later stages of the JUSTAS project. Consequently, the USAF has acquired a large body of first-hand knowledge and experience on the human factors challenges associated with UAV combat operations. A full trip report for this visit is presented in **Annex A**. Mock-up figures of the MQ-1 Predator UAV are presented in **Annex B**.

3.1 Organizational Influences

Within the CF there are three levels of organization: tactical (e.g., Wing Command), operational (e.g., Command 1 Canadian Air Division/Canadian North American Aerospace Defence Command Region), and strategic (e.g., National Defence Headquarters) (Department of National Defence, 2007). System-wide human factors problems that are prevalent in the organization are referred to as organizational influences that define the environment in which CF members perform their daily tasks. According to the CF HFACS, organizational influences are divided into three categories: Organizational Resource Management, Organizational Climate, and Organizational Process (Department of National Defence, 2007). Organizational Resource Management refers to the management, allocation and maintenance of organizational resources such as personnel, financial and equipment/facilities that adversely affect safety. Organizational Climate refers to a class of organizational variables such as organizational structure, policies, and culture that adversely influence worker performance and safety. Organizational Processes refers to the formal processes by which tasks are accomplished in the organization, including factors of operations, procedures and oversight/guidance.

Organizational influences are now playing a major role in causal factors. This emphasizes the importance of following correct airworthiness procedures and standard air force practices when introducing equipment into service. For example, the MQ-9 Reaper used by the USAF was in combat for almost four months before Operational Test and Evaluation even commenced on the platform. All too often operational expediency has driven shortcuts. A CF UAV liaison officer expressed the opinion that these shortcuts resulted in mishaps in which the causal factors may have been misinterpreted as other than organizational. Some organizational influences are discussed below.

3.1.1 Command and Control

Crew coordination is the "timely and adaptive sharing of information among crew members" (Gorman et al., 2006, p. 487). Crew coordination requires an appropriate information flow between crew members (Gawron, 1998), which facilitates effective communications in multi-operator environments that are important to support team performance (Helmreich, Merritt, & Wilhelm, 1999). As a result of aviation mishaps attributed to a lack of or ineffective communication, crew resource management (CRM) programs were established to emphasize the importance of 2-way information exchanges to flight-deck safety (Wickens & Hollands, 2000). Co-ordination of crew activities through communication is also crucial to success in UAV operations (Gugerty, DeBloom, Walker, & Burns, 1999). For example, poor crew coordination was identified as one of the leading causes of mishaps for the Shadow and Hunter UAV used by the US Army (Manning et al., 2004). In another example, statistics from U.S. Navy Safety Center showed that 13% of human-factors-related Pioneer (RQ-2) mishaps from 1986-2002 cited crew coordination issues (Williams, 2004).

In addition to crew coordination issues, UAV pilots have reported instances where different commands of conflicting mission objectives have led to ineffective communication. Specifically, UAV pilots interviewed at Creech USAF Base (**Annex A**) reported that there did not appear to be a uniformed method for outside agencies to request immediate changes to an ongoing UAV mission. For example, when sensor data, provided to different commands, no longer supports a particular command's mission objectives, the tendency is to call into the squadron or even directly into the GCS in an attempt to "steer" an ongoing UAV mission, despite the objectives of the other commands. Different commands have slightly different mission objectives and hence different intelligence needs. Further, sensor data are valuable to the US and coalition force operations and in fact have saved the lives of soldiers on the ground by providing superior intelligence of enemy movements and activities. This tendency to call into the squadron or directly into the GCS is increased if the UAV is the only armed close-air-support vehicle within range of a troop in a contact event. In another example, UAV personnel have reportedly been directed to take-off or orbit in deteriorating weather conditions despite objections by the UAV "pilot".

Multiple requests from outside the immediate chain-of-command result in frequently changing and conflicting mission objectives for UAV operators (**Annex A**). This leads to UAV operators feeling a lack of ownership of the mission and leads to increased frustration and stress. For UAV operators who are former manned flight pilots, this sense of frustration is more pronounced because they are accustomed to being completely in charge of both the aircraft and the mission once the mission has been launched. To help increase operational effectiveness, there is a requirement to develop policy for outside agencies to request immediate changes to an ongoing UAV mission.

3.1.2 Handoff Procedures

The transfer of control of the UAV between operators is usually required at some point during a long-endurance flight because of the limited range of the control station and/or stationary pilot (Williams, 2006). There are generally three methods for carrying out the handoff: (1) from one GCS to another GCS; (2) from one crew of operators to another crew within the same GCS; and (3) from one operator to another operator of the same crew (McCarley & Wickens, 2005). Maintaining SA is required during a handoff procedure. Indeed, UAV mishaps have occurred either directly or indirectly as the result of handoffs (McCarley & Wickens, 2005; Tvaryanas, 2006; Williams, 2004, 2006). For example, during one handoff procedure, the mishap crew did not accomplish all of the checklist steps in the proper order, resulting in turning off both the engine and the stability augmentation system of the aircraft (Williams, 2004). Transfer of control problems generally arise because the receiver of control is not always fully aware of the status of the system (Williams, 2006). Further research is required to ensure that the GCS interface displays all critical system parameters to the pilot during the transfer (Williams, 2006).

3.1.3 UAV Crew Selection

Over the past ten years, the role of UAVs in military organizations has expanded from surveillance and reconnaissance for gathering intelligence on potential threats to a decisive weapon used in combat for eliminating insurgent activity (Fahlstrom & Gleason, 2009). This technology has led to the creation of new jobs that are unique to military organizations. In the case of the Predator UAV, the crew consists of three operators: mission commander (MC), air vehicle operator (AVO), and payload operator (PO).

The role of the MC is to develop an initial mission plan based on the tasking organization or command unit’s requirements (Gugerty, 2004). This includes the basic flight and navigation plan and the selection of way points. Adaptation of the initial plan in real-time is likely necessary to accommodate unforeseen events such as local weather changes, new targets, new threats, or any other new information pertinent to the mission at hand. When a target is detected, it is the responsibility of the MC to direct the AVO on how to best approach and achieve desired mission outcomes. Communication with the command units is performed through the MC.

The primary responsibility of the AVO is to fly the aircraft and maintain stability and control of the aircraft at all times during the mission (Gugerty, 2004). On some UAVs, control surfaces such as flaps, ailerons, elevators and throttle are typically manipulated manually through standard flight controls (e.g., stick, rudder pedals, and yoke). Certain aspects of the flight may also be automated. For example, an autopilot is typically available to the AVO and if enabled, the AVO assumes a supervisory role by monitoring and programming the onboard autopilot rather than the manual flying of the aircraft.

The PO is tasked with controlling the cameras, radar, munitions, or any other non-flight equipment used when tracking the target as defined by the mission requirements (Gugerty, 2004). For example, if the mission is primarily one of image data collection with the use of an onboard video camera, the PO's main charge is to optimize the positioning of the camera to capture as much high quality video as possible on the tracked target.

Given that UAVs are remotely operated, researchers have investigated the amount of flying experience required to operate the Predator UAV. Schreiber, Lyon, Martin, and Confer (2002) performed a study to compare the speed and accuracy of the prior flight experience of military and civilian pilots on learning to fly the RQ-1A Predator UAV. The seven pilot groups tested were: (1) experienced USAF Predator pilots; (2) experienced USAF pilots recently selected to fly the Predator; (3) students recently completing USAF T-38 training; (4) students recently completing USAF T-1 training; (5) students recently completing single-engine instrument training at Embry-Riddle Aeronautical University (ERAU; Daytona, FL); (6) students recently completing requirements for a private pilot's license; and (7) Reserve Officer Training Candidate (ROTC) students at ERAU who intend to be USAF pilots but who had no flying training or experience. All participants completed a series of multimedia tutorials on basic principles of flight and procedures for operating the Predator, and then were assessed for stick and rudder skills while carrying out mission scenarios on a RQ-1A Predator UAV simulator. Both qualitative and quantitative analyses were conducted to assess performance.

The results show that experienced Predator operators performed better than the other groups (Schreiber et al., 2002). The T-38 graduates and civilian instrument pilots performed nearly as well as current Predator selectees on difficult aircraft handling tasks in the simulator, possibly due to some advantages to recent experience flying aircraft (about 150 - 200 hours) that have handling characteristics similar to the Predator. The ROTC group performed poorer than the other groups despite declarative and procedural training and supplemental instructional documents.

To help identify personnel that may qualify for UAV operator positions, Weeks (2000) examined differences in UAV operator qualifications for UAVs operated by the US Department of Defense. The UAVs studied were the US Navy and US Marine Corps Pioneer, US Army Hunter, USAF Predator and Global Hawk, and British Army Phoenix. The British Army Phoenix was included as an example of another nation's UAV capability. These five UAVs represent a diverse set of UAVs and provide a frame of reference for investigating operator qualifications. Weeks (2000) detailed the qualifications and special training requirements by UAV type and crew member position. Controversy in operator qualifications was identified by differences across US military services. This study highlights the fact that identifying operator qualifications for a diverse set of UAVs is difficult due to differences in UAV design and operation

Some military organizations do not require previous pilot experience as a mandatory criterion for operating the MQ-1 Predator, and MQ-9 Reaper. For example, candidates with no prior pilot or aircrew experience were passed through the USAF's training pipeline and some have since flown supervised combat sorties over Afghanistan (Hoyle, 2010). In another example, two students with no previous flying experience from the United Kingdom (UK) Royal Air Force were permitted to transition onto the Predator after having logged hours on the Grob G115 Tutor and weeks of simulator work on the Shorts Tucano T1 (Hoyle, 2010). In a third example, the US

Army, Navy, and Marine Corps have employed trained non-commissioned members as UAV pilots on roughly equivalent airframes (Weeks, 2000). These findings have implications for CF UAV crew selection.

Currently, the CF does not have a systematic method to select the crew of MALE UAVs. As an example, UAV crews were selected based on conformance with CF policies for the 2004 CF Atlantic Littoral ISR Experiment (ALIX) that investigated the employment of a MALE UAV and a variety of other sensors in a littoral environment using domestic security and peace support scenarios (Newton et al., 2005). These policies required that CF pilots (preferably transport or Maritime Patrol background Instrument Check Pilots) be considered due to the experimental nature of ALIX. Thus, the crew selection focus was on CF policy and to a lesser degree on the required competencies to operate UAVs. Notwithstanding the amount of previous pilot or aircrew experience, the CF must establish a training pipeline to train personnel selected as UAV operators.

For the CF, recruitment, training, and retention of sufficient numbers of manned flight pilots presents a challenge. This problem could become worse if pilots originally selected for manned flight are redirected to UAV operations; redirecting the career of an individual who has aspirations for manned flight to UAV flight could result in job dissatisfaction. This could decrease motivation and performance, potentially reducing operational effectiveness. Under the draft JUSTAS concept of operations, there is no clear indication of the trades required to fulfill the various UAV operator roles. In the past, tactical helicopter pilots were used to fulfill the AVO and PO roles. Currently, air navigators have been selected to lead future UAV operations for the CF. Air navigators, referred to as air combat systems operators (ACSOs), are argued to have the required background to be effective UAV operators. ACSOs have the "air sense, tactical decision-making experience, practical knowledge of air regulations and orders, and familiarity with remote sensor operations" (Chaloux, 2008, p. 10). This stresses the importance of the selection of suitable individuals with the required skills and knowledge to fulfill UAV roles.

The method for fulfilling UAV roles must be identified. When job incumbents exist, one approach that could help identify the skills and knowledge required for carrying out a job is to perform a cognitive task analysis (CTA). CTA is a group of task analysis methods that specifically uncovers the cognitive processes required to accomplish a certain task (Crandall, Klein, & Hoffman, 2006; Klein, & Militello, 2001). These methods may be used to determine the cognitive processes involved in operating the CU-170 Heron UAV used by the CF in the ongoing mission in Afghanistan, which could also help determine the skills and knowledge that a UAV operator should possess. For JUSTAS, job incumbents do not exist. The skills and knowledge required to operate a MALE UAV in support of the JUSTAS project must be identified to develop a CF military occupation classification (MOC). The process for selecting UAV crews begins with a mission, function, task analysis (or equivalent analysis such as a hierarchical goal analysis) in order to identify the key tasks (Farrell, Hubbard, & Culligan, 2006). Predicted skills and knowledge could then be matched to predicted tasks. These predicted job elements could then be compared to existing job elements within the CF military occupational structure identification database (MOSID) and produce an initial list of jobs that come closest to matching the predicted job elements. Farrell et al. (2006) investigated an alternative crew selection method that could be used to staff UAVs. The crew selection method is based on matching existing job elements (task and knowledge statements) to predicted job elements generated from a UAV scenario. They developed a job similarity index (JSI) to predict the degree to which existing job elements matched predicted job elements for any CF UAV crew position or member; subsequently they carried out an initial experiment to determine the relationship between JSI and performance in a UAV scenario. The results showed that there were indications of a relationship between the JSI and most measurements of performance (task completion, cognitive ability, training proficiency, and SA). This study showed some promise that their JSI crew selection method would be a viable alternative for selecting crews particularly when job incumbents do not exist. The consequence of failing to select personnel with adequate skills and knowledge to operate MALE UAVs for JUSTAS could compromise the successful completion of the mission, thus reducing CF operational effectiveness.

3.2 Operator Influences

As noted by Herz (2008), the period covering fiscal years 1997 - 2003 cited mechanical and technical issues as contributing factors in Predator UAV mishaps. Fiscal years 2004 - 2006 rarely cited mechanical errors in mishap reports as primary causes for Class A Predator UAV mishaps. Given the increase in human error as a contributing factor in Predator UAV mishaps, the effects of operator influences on UAV operations need to be investigated. This section discusses the effect of fatigue and vigilance on operator performance.

3.2.1 Fatigue

Pilot fatigue arises from unpredictable work hours, long duty periods, circadian disruptions, and insufficient sleep that are commonplace in both civilian and military flight operations (Caldwell et al., 2009). UAV operator fatigue generally arises from the requirement to man the GCS for as long as the UAV is airborne. Recent increases in long-endurance UAV operations within the USAF have necessitated the routine implementation of shift work schedules to man the GCS around-the-clock (Tvaryanas, Platte, Swigart, Colebank, & Miller, 2008). Similar trends in operational requirements in the CF have necessitated shift work schedules.

Tvaryanas and Thompson (2006) assessed fatigue in USAF shift worker populations, defined as populations who worked “at times other than normal daylight hours of approximately 7:00 a.m. to 6:00 p.m.” (Rosa & Colligan, as cited by Tvaryanas & Thompson, 2006, p. 1411). In examining factors such as work context, shift system details, work/rest guidelines and participation in deployed operations, these investigators found that MQ-1 Predator UAV crew members and maintenance personnel experienced greater fatigue than manned aircraft crew members and maintenance personnel. Additionally, crew members, including pilots and sensor operators, were equally fatigued as maintenance personnel, as were those stationed at home base versus those deployed in current military operations.

Since some UAV missions may span several months, operators must accommodate to shift work schedules for long periods of time. Thompson et al. (2006) assessed MQ-1 Predator crews involved in rotational shift work during a period of sustained operations. They found that MQ-1 Predator crews experienced higher levels of fatigue, emotional exhaustion and burnout relative to aircrews from other “high demand/low density” weapon systems that are subject to frequent and lengthy deployments. Decrements in mood, cognitive and piloting performance, and alertness were observed over the duration of a shift and prevalent across all shifts and shift rotation schedules. Furthermore, the adverse effects of shift work were found to be more pronounced on both day and night shifts relative to evening shifts and on rapid shift rotation schedules relative to slow shift rotation schedules.

A follow-on study evaluated shift work-related fatigue among MQ-1 Predator crew members. Tvaryanas et al. (2008) evaluated crew members one year after the squadron changed shift work schedules where pilots were transitioned from a weekly rotation schedule to a monthly rotation schedule. In addition, the number of consecutive days off was increased from two to three in order to provide greater opportunity for recovery sleep. The results of this study were indicative of chronic fatigue in spite of the change in shift work schedule. Of the 66 crew members who completed a questionnaire to evaluate shift-work-related fatigue, 40% reported a moderate to high likelihood of falling asleep in the GCS while operating a weaponized, remotely piloted aircraft. Pilots were found to have higher mental fatigue scores than sensor operators, suggesting a possible task-related contribution to their fatigue. Further, modeling and simulation were used to evaluate shift work schedules, which revealed that there did not appear to be an alternative schedule that offered a significant advantage. The results of these two studies are supported by anecdotal evidence from Predator crew at Creech USAF Base who reported high levels of fatigue (**Annex A**).

Shift workers face circadian disruptions because individuals must adapt to unusual work schedules and sleep-wake patterns (Costa, 1999). Around-the-clock shift work necessitates that some individuals, including night shift workers, adjust their sleep-wake patterns so that they work during the night and sleep during the day. Failure to adjust the circadian rhythm can lead to circadian desynchronization, whereby an individual might experience a wide variety of symptoms including fatigue, sleepiness and insomnia. A rotating shift schedule puts additional pressure on the circadian system to continuously readjust, with permanent night workers experiencing similar pressures of “changeover” since diurnal family and social cues often compel workers to revert to a diurnal pattern during rest days. Diurnal sleep is often difficult to initiate and maintain due to biological circadian factors such as body temperature, and unfavourable environmental conditions including light and noise. Day-sleep is also typically 1 - 4 hours shorter than night sleep, resulting in cumulative sleep deprivation over successive days, and eventual long-term exhaustion (Muecke, 2005). In summary, diurnal sleep is decreased in quantity and in quality, which may lead to fatigue.

Fatigue has serious implications for UAV pilots such as reduced decision making capability, reduced memory performance, and decreased ability to focus during vigilance tasks (Thompson et al., 2006). Indeed, fatigue was cited in 13% of the most serious class of Air Force aviation mishaps during fiscal years 1972 - 2000, as found from an Air Force Safety Centre study (Tvaryanas & Thompson, 2006). Shift work and night work has also been strongly linked to an increase in workplace accidents and injuries (Folkard and Åkerstedt, 2004). These findings suggest that shift-work-related fatigue decreases UAV operator effectiveness and increases the probability that an operator will miss a system warning or commit an error, potentially leading to a catastrophic event. In addition to operator performance levels, health issues associated with shift work and fatigue include psychosomatic disorders such as colitis, gastroduodenitis, and peptic ulcers (Costa, 1999). Chronic fatigue can also lead to hypertension, and ischemic heart diseases. Finally, chronic fatigue can result in changes in behaviour and personality, leading to persistent anxiety and clinical depression that may require treatment with psychotropic medications.

The performance and health issues associated with fatigue and shift work must be addressed to maintain operational effectiveness. In addressing these issues, the CF must consider conditions that UAV crew will experience in near and long-term operations. For near-term operations, the entire UAV detachment will be deployed forward for a standard six or nine month tour. Operations where the entire detachment is deployed allow personnel to be given an extensive period of rest in Canada prior to redeployment. However, the CF will require sufficient operators to ensure a continual deployment cycle over the course of an operation. While deployed, the detachment will have the sole focus of conducting UAV operations around-the-clock. UAV crews will be subjected to the same physical and mental stress as other CF members on deployment in an active theatre of operations, but also have the additional stress of conducting a very complex task through a rotating shift schedule.

In the long-term, under the JUSTAS concept of operations, the CF will be moving toward the model that the USAF is currently using. The Main Operating Base (MOB) will push forward the Launch and Recovery Element (LRE) for a 6 - 9 month deployment with a Main Control Element (MCE) kept in Canada. The LRE will be subjected to the same deployment stressors (shift work and fatigue) as if the entire detachment had been pushed forward (i.e., as if they had been deployed overseas). As the JUSTAS project develops, the CF may pursue two or more lines of tasking as a result of conducting simultaneous deployed and domestic operations. In addition, MCE personnel will be subjected to all the shift work stressors now affecting the USAF, and will likely exhibit the same fatigue and associated health reactions. If the requirement to deploy to the LRE is rotated amongst MCE personnel, then depending on manning levels, there is the potential that personnel returning from theatre may not receive sufficient rest, potentially reducing operational effectiveness.

Personnel interviewed at Creech USAF Base (**Annex A**) stated that the optimal number for a fully operational UAV crew is nine to effectively conduct two continuous lines of tasking in two different areas of interest (AOI). This provides adequate scheduling flexibility to ensure that a crew can be granted time for vacations, sick days, personal issues, and crew rest days. If there is a reduction of crew personnel below nine, then there are fewer UAV crew members available to cover shifts. The lack of personnel increases the frequency of the rotating shift work schedule, which increases crew work load. These conditions could result in increased fatigue, reduced morale, increased crew burn-out, increased health issues, and could lead to increased incidence of voluntary release from the CF.

There are countermeasures to mitigate the detrimental effects of fatigue. Some of these may not be practical to implement in the GCS. One such countermeasure is rest breaks. Rest breaks help maintain efficiency over long periods of up to 18 hours, benefit mood, and increase productivity (Penn & Bootzin, 1990), and mitigate the vigilance decrement (Pigeau, Angus, O'Neill, & Mack, 1995). However, the provision of rest breaks in the GCS requires a handoff procedure. Handoff procedures were cited as contributing to mishaps (McCarley & Wickens, 2005; Williams, 2004, 2006) (see Section **3.1.2**). To help address some of the issues that UAV operators in the CF may encounter due to shift work, some countermeasures known to mitigate fatigue are presented below.

The following are examples of countermeasures that can be implemented during a shift:

- Lighting: Bright light has acute arousal effects that can be used during shifts. For instance, bright light therapy, often used to mitigate the effects of seasonal affective disorder, primarily affects energy levels as it rapidly increases alertness (Lindsley & Buchan, as cited in Penn & Bootzin, 1990). The arousal mechanism may involve light-induced activation of reticular formation or light-induced suppression of melatonin release during mid- to late-evening (Caldwell et al., 2009). Room light levels of 100-200 lux have been shown to be effective in increasing subjective alertness and reducing slow eye movements, with short wavelength light having the greatest alerting effect (Caldwell et al., 2009).

- Noise and Music: The effect of noise and music on performance varies with volume, noise quality, and task demands. Generally, meaningful and unpredictable sounds (e.g., speech, traffic noise, and music) at a moderate volume are the most effective at enhancing performance. The effects of sound are also task dependent, as sounds that enhance performance for a low-demand task can hinder performance in a high-demand task. For music, variation in tempo, rhythm, instrumentation, and a random presentation schedule have the most stimulating effects (Penn & Bootzin, 1990).

The following are examples of countermeasures that can be implemented before and/or after a shift:

- Prophylactic Naps: Prophylactic naps prior to a shift can improve performance (Caldwell et al., 2009), with longer pre-shift naps resulting in better performance. Naps should be as long as possible, and should occur during circadian periods most natural to sleep (i.e., early afternoon or predawn hours according to the body clock). Following a nap longer than 40 minutes, a wake up period of at least 30 minute should be allotted to pass any sleep inertia effects before performing a safety-sensitive task.

- Sleep Hygiene: Sleep hygiene includes information regarding the effects of biological, behavioural and environmental factors that affect sleep (Penn & Bootzin, 1990). The acquisition of a sufficient quantity of high quality sleep is of utmost importance in mitigating fatigue (Caldwell et al., 2009). To help optimize available sleep opportunities, education in sleep hygiene should be provided. Topics should include sleep deprivation, sleep scheduling, and circadian rhythms. Information on the effects of naps, caffeine, smoking, and alcohol should be presented, along with tips on how best to regulate noise, light and temperature within the sleeping environment (Penn & Bootzin, 1990). Adherence to good sleeping habits and proper modifications to the sleeping environment can encourage successful adaption to shift work.

- Pharmacological Intervention: One key pharmacological intervention is the use of hypnotics (Paul, Gray, Kenny, & Pigeau, 2003). Hypnotics such as zaleplon, zopiclone and temazepam, which are approved by Health Canada, can facilitate sleep in suboptimal environments, individual states or circadian phases (Caldwell et al., 2009). Although there are some caveats to the use of hypnotics, including the presence of lingering effects on performance after one awakens from the sleep period and the effects of repeated use (Krueger, 1989), restricted and well-planned use of a safe hypnotic can be a preferable alternative to sleep deprivation or alcohol-induced sleep.

- Circadian Entrainment: Circadian entrainment uses techniques to phase-shift circadian rhythms to align with night work and day sleep schedules (Crowley, Lee, Tseng, Fogg, & Eastman, 2003). These techniques include melatonin (Paul et al., 2009a) and light therapy (Paul et al., 2009b).
    - Melatonin is a hormone naturally produced by the pineal gland. It plays a role in regulating the sleep wake cycle and its level follows a circadian rhythm (Paul et al., 2009a). Melatonin was not approved for over-the-counter sale in Canada and thus required regulatory permission from Health Canada to support operational requirements (Paul et al., 2004). Currently, the Natural Health Products Directorate within Health Canada has regulatory control of approximately 50 different melatonin formulations approved for over-the-counter sale in Canada (Paul, personal communication, October 4, 2010). Ingestion of exogenous melatonin has mild hypnotic effects and can induce circadian phase shifts (Paul et al., 2009a). For phase advance, melatonin should be administered in the late afternoon or evening (e.g., 4:00 p.m.). For phase delay, melatonin should be administered in the morning upon awakening (e.g., 6:00 a.m.). Higher melatonin doses (e.g., 5 mg) are more efficacious than lower doses (e.g., 0.5 mg). However, if timed appropriately, lower doses can be as effective as higher doses.
    - Light therapy involves the use of a phototherapeutic treatment device to suppress the body's natural evening time release of melatonin. Its effectiveness is dependent on the emitted wavelength(s), source intensity, distance, timing, and duration. For individuals with a dim light melatonin onset at 9:00 p.m., the optimal period for a single short wavelength light treatment would be between 6:00 - 8:00 a.m. for phase advance and 2:00 - 3:00 a.m. for optimum phase delay (Paul et al., 2009b).
- Physical Exercise: Regular aerobic exercise at appropriate levels and timing has been shown to improve sleep quantity and quality (Caldwell et al., 2009). Additionally, exercise can help facilitate sleep/wake cycle delay when the circadian rhythm needs to be adjusted. Caldwell et al. (2009) recommend at least 30 minutes of aerobic exercise every 24 hours in the late afternoon. Exercise should be performed at least 2 hours prior to bed time to allow the body to cool.

3.2.2 Vigilance

Vigilance, also termed sustained attention, is defined as "the ability of observers to maintain attention and remain alert to stimuli over prolonged periods of time" (Parasuraman, Warm, & Dember, 1987, p. 11). Maintaining sustained attention is of concern to human factors practitioners because automation has fundamentally changed aspects of work (Parasuraman & Riley, 1997). As Sheridan (1987) noted, the development and utilization of automatic control and computing devices for the acquisition, storage, and processing of information has altered the role of the human operator in many work settings from that of active controller to that of executive or supervisor (see Section **3.3.1**). Consequently, vigilance has become a crucial component of human performance in many work environments where automated systems are common. These include military surveillance, ATC, cockpit monitoring, industrial quality control, and medical monitoring (Warm, Parasuraman, & Matthews, 2008). Mishaps have been attributed to a failure of maintaining vigilance in automated systems (Molloy & Parasuraman, 1996). Maintaining vigilance is important in the control of UAVs because the operator role is changing in monitoring UAV automation. The failure of UAV operators to sustain attention for an extended period of time could increase the probability that critical signals (e.g., system malfunctions, and enemy targets) will not be detected or increase the time taken to respond to critical signals, which could have severe consequences on operational effectiveness. Hence, understanding the factors that influence vigilance performance is a critical human factors concern (Warm et al., 2008).

The laboratory study of vigilance dates back to World War II. It was prompted by the British military's need to understand the decline in performance of airborne radar operators engaged in antisubmarine warfare who missed blips on the plan position indicator radar screen after only about 30 minutes on watch. Mackworth (1950) was commissioned by the Royal Air Force in 1948 to address the observed decline in radar operator performance. He devised the "Clock Test", which consists of a single rotating black pointer on a white background. The pointer moved clockwise to the next position once every second. Occasionally, however, the pointer "jumped" twice the normal distance. The "double jump" of the pointer was the target, and the participant's task was to detect its occurrence. Twelve targets had to be detected per 30 minute period of the two-hour watch, appearing at intervals from 45 seconds to 10 minutes. Detection efficiency, as measured by the number of missed targets, deteriorated rapidly after the first 30 minutes, which confirmed the results of real radar operations. The failure to detect targets is not restricted to the visual modality. In a separate experiment, Mackworth (1950) found that the incidents of missed targets for an auditory task also increased as a function of time on task.

Following Mackworth's (1950) pioneering studies, investigations on factors that affect operator attentiveness for the detection of critical signals have been conducted using a myriad of experimental paradigms and performance measures (for reviews see Davies & Parasuraman, 1982; See, Howe, Warm, & Dember, 1995; Warm, 1993). The results of these studies have generally confirmed Mackworth's observation of a decline in observer performance (called the "vigilance decrement") over the watch. The decrement is reflected by a decrease in detection rate, an increase in the number of false alarms and incidents of missed targets, and a slower response time to targets that are correctly detected (Warm, 1984). A smaller degradation in performance is expected in an auditory watchkeeping task than its visual counterpart because the critical signals may be perceived aurally even when the operator's eyes are directed elsewhere (referred to as decoupling) (Warm & Jerison, 1984).

A view held for many years was that the decrement could be attributed to signal detection theory measures of the user's sensitivity (d') and the user's own criterion (β) (Macmillan & Creelman, 1991), whereby a drop in arousal can cause a decrease in d' as to the presence of the target or a shift in β as to what sensory inputs constitute a target (Davies & Parasuraman, 1982; Warm, 1984). However, recent evidence suggests that the information processing demand of a vigilance task is high and the decrement reflects the depletion of information-processing resources over time (Helton et al., 2005; Warm & Dember, 1998; Warm, Dember, & Hancock, 1996). For example, Warm et al. (1996) found that ratings of perceived mental workload increased linearly over the course of the watch as measured by the National Aeronautics and Space Administration Task Load Index (NASA-TLX) (Hart & Staveland, 1988). Specifically, workload ratings across experiments fell within the middle to upper levels of the NASA-TLX scale (Warm et al., 1996). Further, studies using physiological and self-report measures show that vigilance tasks induce stress (Warm et al., 2008). In addition, given the constrained and repetitive nature of vigilance tasks, most observers consider vigilance tasks to be boring and monotonous (Thackray, Bailey, & Touchstone, 1979; Thompson et al., 2006).

Boredom is associated with feelings of increased constraint, repetitiveness, unpleasantness and decreased arousal (Finomore, Matthews, Shaw, & Warm, 2009). Boredom has been shown to negatively affect morale, performance, and quality of work (Thackray, 1981). Participants who were asked to rate themselves on five mood dimensions before and after a vigilance task reported that they were more strained and less attentive after the vigil compared with the pre-test measures (Thackray et al., 1979). Thompson et al. (2006) found that participants who reported greater subjective task-related boredom tended to have slower reaction times on a simulated UAV manoeuvring task. In operational settings, hazardous states of awareness such as absorption (i.e., oblivious to all but a few elements in the present environment) and preoccupation (i.e., preoccupied with thought related to matters outside the present situation) by an individual can be detrimental (Pope & Bogart, 1992). For example, narratives in the Aviation Safety Reporting System database contain descriptions of civil transport flight crew members becoming “complacent” and succumbing to boredom (Pope & Bogart, 1992).

The gravity of missed detections has motivated researchers to investigate countermeasures that could sustain “acceptable” performance levels (Arrabito, Able, & Lam, 2007; Davies & Parasuraman, 1982; Matthews, Davies, Westerman, & Stammers, 2000). Examples of countermeasures include rest breaks (Colquhoun, 1959; Mackworth, 1950; Pigeau et al., 1995), direct supervision (Bergum & Lehr, 1963; Fraser, 1953), music (Fox & Embrey, 1972), and providing knowledge of results (McCormack, 1959). For example, the provision of periodic rest breaks throughout time on task or assigning another activity can have beneficial effects on monitoring performance (Davies & Parasuraman, 1982; Mackworth, 1950; Pigeau et al., 1995). Mackworth (1950) recommended that the rest break should occur within the first 30 minutes of the watch. Pigeau et al. (1995) observed that rest breaks help mitigate the vigilance decrement in the detection of aircraft entering designated air space. The provision of rest breaks for UAV crew would necessitate the transfer of control of the UAV (see Section **3.1.2**). However, there is evidence for an acute decrement in crew SA in the transfer of control of the UAV (Tvaryanas, 2006).

Investigators have explored countermeasures to mitigate the vigilance decrement for UAV control. For example, Gunn et al. (2005) assessed vigilance performance for target acquisition in a simulated UAV control environment; observers were alerted to the presence of hostile aircraft through the use of sensory or cognitive display formats. The critical signals for detection in a sensory display are changes in the physical attributes of the stimuli (e.g., lights and tones), whereas the critical signals for detection in a cognitive display are more symbolic (e.g., series of digits are presented and the observer must detect a specified sequence such as three consecutive odd digits, all of which are different) (Warm, 1984). Relative to a cognitive display, Gunn et al. (2005) found that a sensory display resulted in higher enemy threat detections, fewer false alarms, and faster response times for detecting enemy threats. Also, a sensory display imposed a smaller workload than a cognitive display format. In another example, St. John and Risser (2009) used an eye tracker and an electroencephalographic system to compute an index of task engagement during a vigilance task. An auditory secondary task was activated when inattention was detected according to a preset rate, or randomly throughout the session. The researchers found that there were 17% fewer target misses overall in the inattention condition than in the random condition. The results from Gunn et al. (2005), and St. John and Risser (2009) suggest that the JUSTAS project should perform further research to determine the practical applications of these factors for mitigating the vigilance decrement for UAV control.

3.3 Human-System Integration Issues

For UAV operators, the human machine interface (HMI) represents the fundamental point of interaction and the means of communicating knowledge and information between the system and the individual operating the UAV. An optimized HMI is critical for the effectiveness of human performance, the maintenance of SA during a mission, and the success of operations. Additionally, it provides the primary means of controlling the level of UAV autonomy, which dictates the extent to which the human-machine system makes sound mission decisions and operates safely. The following three sections discuss four areas of research that need to be further investigated to create an optimized HMI for the JUSTAS project.

3.3.1 Automation and Autonomy

While early UAVs were planes remotely manned from the ground, today's UAVs are highly automated and to some extent, they are autonomous. UAVs can be directed to follow a pre-programmed mission; they can fly to designated way points, fly specific patterns, correct for course deviations and hold above a particular coordinate or target. Some UAVs can perform automated take-off and landing (e.g., the CF's CU-170 Heron). UAVs with autoland capabilities can detect problematic approaches and decide to abort landings. UAVs may also have a return-to-base capability if a data link loss is experienced.

UAV developers argue that automation and autonomy provides several benefits: (1) increased flight safety; (2) simplified operations; (3) lower operating costs; and (4) reduced operator workload (Attar, 2005). For example, to help reduce human error on UAV take-off and landing (Williams, 2004), the Global Hawk and Army tactical UAV systems have moved to automated take-off and landing technology (Defense Science Board, 2004). According to the Defense Science Board, automated take-off and landing have proved reliable across a wide range of UAVs. Undoubtedly, well designed automation can provide many benefits. However, automation can also result in several unintended consequences, both for the human operator using the automation and for the organization incorporating it (Lee, 2008; Parasuraman & Riley, 1997).

One consequence of automation is the altered role of the human operator. The operator's task changes from manual control of the UAV to one of supervisory control of the automation (Parasuraman, Molloy, Mouloua, & Hilburn, 1996; Sheridan, 1987). The human operator must now monitor the automation to ensure that it performs effectively. In addition, the operator may have to evaluate or finalize automated decisions, diagnose problems, and take over manually when the automation fails. For example, while a UAV can be programmed to take-off, fly a specific mission and land, an operator must still ensure that mission goals are being met, that subsystems are healthy and running normally, and that changing environmental conditions do not interfere with the mission.

For the most part, human monitoring of automation is quite effective but occasional monitoring errors do occur (Parasuraman et al., 1996). For example, pilots using automation may ignore other sources of information that can signal an automation failure as in the case of Eastern Flight 401 that crashed into the Florida Everglades; the crew failed to detect the autopilot disengaging and did not monitor altitude because they were engaged in a possible problem with the landing gear (National Transportation Safety Board, as cited in Molloy & Parasuraman, 1996). In another example, the RQ-1 Predator UAV mishap on April 18, 1999 partially resulted from losing SA. In that mishap, the Predator experienced aircraft icing, leading to loss of engine power. Although the UAV pilots performed recovery procedures, they became too focused on the rarely encountered severe weather conditions, lost control of the UAV, and were unable to recover (Manning et al., 2004).

Another consequence resulting from increased automation is the vast amount of information that needs to be monitored by the operator. As more subsystems become automated, the human operator is generally responsible for monitoring an increasing number of system variables. A UAV GCS interface is knowledge-intensive and at times can generate extremely high workload for the operator due to the amount of information that needs to be monitored. Because the information load is high, attention needs to be placed on the design of the interface which is critical for supporting the monitoring task (Lee, 2008; Woods, 1996). When data are missing from the interface, displayed poorly, or do not match the operator’s goals, operators may miss events, be unable to react to events, or lose SA.

Loss of SA occurs in part because operators take on a passive role in monitoring as opposed to the active role of information processing (Endsley, 1996). Endsley and Kiris (1995) found that participants had lower SA when operating under fully automated and semi-automated conditions versus manual performance. SA is also affected by automation-induced complacency (Endsley, 1996). Complacency occurs when the operator assumes that automation is behaving correctly and thus he/she becomes less vigilant of the automation (although, see Moray, 2000 and Farrell & Lewandowsky, 2000 for alternate explanations). For example, Parasuraman, Molloy and Singh (1993) provided participants with automation that monitored for system malfunctions in a flight simulation task. They found that participants detected fewer automation failures when the automation reliability was high, suggesting that participants became complacent and failed to appropriately monitor system variables.

Automation reliability has a widespread effect on operator attitudes (e.g., trust) and behaviour (e.g., user reliance, monitoring strategies and decision making). In general, when automation reliability is low, operators ignore or abandon the automation (Beck, McKinney, Dzindolet, & Pierce, 2009; Lee, 2008; Parasuraman & Riley, 1997). For example, automation with high false alarm rates is commonly turned off because false alarms are distracting and create high workload

(Bliss & Fallon, 2006; Parasuraman & Riley, 1997). However, high reliability can lead to unforeseen problems because no automation is perfect. The operator becomes overly trusting and reliant on the automation. High trust can lead to automation-induced complacency and the operator can continue to rely on automation, even in circumstances when it does not function appropriately (Lee, 2008; Parasuraman et al., 1993; Parasuraman & Riley, 1997).

Automation decision bias is a specific example of how high automation reliability can affect behaviour. Skitka, Mosier, and Burdick (1999) provided participants with a highly reliable, but imperfect automated decision aid that detected system problems and recommended a course of action. When this automation failed, participants using highly reliable automation made more decision errors. For example, when highly reliable automation missed an event, participants were also more likely to miss the event; when highly reliable automation produced false alarms, participants followed the automation directives. Both these types of errors occurred despite having completely reliable (100%) and contradictory evidence that the automation was incorrect, suggesting an over-reliance on automation.

In addition, over-reliance on automation and complacency appears to interact with workload (Parasuraman et al., 1993). Dixon and Wickens (2006) had participants fly UAV missions under high and low workload conditions. During their missions, system failures occurred. An auditory alert was presented at different levels of reliability to signal a system failure. Under low workload, the reliability of the alerts did not affect system failure detections. However, under high workload, complacency effects were evident. For example, the operators using highly reliable automation were slower at detecting system failures when the automation missed a system failure.

Workload is also a concern because designers and organizations make the incorrect assumption that automation necessarily reduces operator workload (Parasuraman et al., 1996; Woods, 1996). Instead, research has generally found that either there is no reduction in workload, or workload becomes distributed unevenly during a task (Parasuraman et al., 1996). In aviation, Wiener (as cited in Parasuraman et al., 1996) found that automation reduces workload but only during periods when it is already low. During high workload periods, automation can actually increase workload because the operator must now monitor and address the primary task (e.g., troubleshooting an abnormal event) while monitoring the automation. Thus, automation leads to a paradox. Automation is intended to reduce workload, but in the attempt to reduce workload, automation actually increases it, particularly in critical moments like emergencies (Parasuraman et al., 1996). Emergencies are more likely to cascade because highly automated systems tend to be more tightly coupled. Tighter coupling also increases the complexity of problems (e.g., malfunctions) and complicates the detection and trouble-shooting of a problem (Woods, 1996).

In addition to higher workload during emergencies, automation can result in operators who are “out-of-the-loop” and less familiar with the overall system, and therefore less equipped to deal with emergencies (Hawley, Mares, & Giammanco, 2005; Parasuraman, Sheridan, & Wickens, 2000). Operators might also experience a degree of skill degradation. Skill degradation occurs because of disuse. When tasks once performed by operators are substituted with automation, the operator’s skill at performing the task degrades. Skill degradation becomes a particular problem when the automation fails and the operator must return to manual performance. Furthermore, operators may also not have a complete understanding of how the automation operates. The lack of understanding stems from the inherent complexity of complex systems, poor interface design, or inadequate training (Endsley, 1996).

Skill degradation and out-of-the-loop unfamiliarity presents crew selection and training challenges for an organization. Already discussed have been some of the crew selection problems for UAV operators (see Section **3.1.3**). This raises the question of whether or not UAV operators need to be pilots. Arguments can be made on both sides of the issue. If the UAV is highly automated, the operator's task is similar to that of supervisory control and does not likely need to have the same training as a pilot. However, when problems occur, a pilot who understands the mechanics of flight and avionics might be better equipped to handle the problem.

The unforeseen consequences of automating UAVs will likely pose challenging problems for the CF. Despite the fact that these automation problems have existed for some time (e.g., Bainbridge, 1983), the appeal of automation and its proposed benefits have overshadowed the potential consequences. "Perfect" automation is desirable because it can provide safer, more efficient and less expensive operations, but these benefits are rarely achieved. When automation is introduced, it changes the role of the operator and its effect on the entire system, often creating new complexities.

The extent that these complexities will affect the CF will depend in part on the tasks being automated and the level of automation (Parasuraman et al., 2000). A low level of UAV automation implies that the UAV operator will take on detailed UAV piloting responsibilities, whereas in a higher level of UAV automation situation, the UAV operator's piloting role will be close to that of a supervisory situation or an air traffic controller. Currently, the CF CU-170 Heron is highly automated; specifically, it can fly pre-programmed missions, and has automated take-off and landing capability. As UAVs become even more automated and autonomous, the CF can expect to encounter more of these unintended automation problems.

3.3.2 Multimodal Display for Ground Control Station (GCS) Interface

One of the primary consequences of the physical separation between operators and the UAV is that the UAV operator is deprived of a range of sensory cues available to the pilot of a manned aircraft (McCarley & Wickens, 2005). Information about the environment in which the UAV is inhabiting is provided to the UAV operator only by onboard sensors via a data link. This consists primarily of potentially degraded visual imagery covering a limited field of view. Loss of sensory cues include ambient visual input, kinaesthetic/vestibular information, and sound. Such information can provide pilots with cues to the speed of travel, banking angle, aircraft tilt, the air, ground and sea elements in the vicinity, weather conditions, and engine health and status (Hopcroft, Burchat, & Vince, 2006). In addition, the visual information that is available may not be in real-time (McCarley & Wickens, 2005). This inhibits real-time control that creates temporal and spatial uncertainty for operators (Mouloua, Gilson, Daskarolis-Kring, Kring, & Hancock, 2001).). For example, lag in camera image update times due to bandwidth limitations affect dynamic tasks such as target tracking (van Erp & van Breda, 1999). Moreover, the impoverished cues could impair operator decision making because the nature of a remote environment does not integrate the operator and the vehicle in the same way as a manned aircraft. Errors of misperception caused by erroneous visual cues accounted for 10% of UAV mishaps in which operator error was a causal factor (Tvaryanas et al., 2005). For example, Predator UAV pilots had difficulties landing because of their restricted 30º field of view, which prevented them from seeing the ground (Pederson, Cooke, Pringle, & Connor, 2006). This problem is further explained by a former RC-135 pilot who commanded a forward-deployed take-off and landing unit in Iraq; this pilot stated that “the combination of not being aboard the airplanes so you can't hear the engines spool up, you don’t feel the ground rush, combined with you having no peripheral vision because you're looking through a nose camera and you have to do a purely visual interpretation of your instruments” (Hodges, 2009).

Specifically, an account of UAV landing that resulted in a mishap was reported. The details of the events leading to this mishap are described in the following report: “The mishap pilot misjudged the [remotely piloted aircraft] height above touchdown and confused the initial bounce with a normal aircraft response to his flare inputs. This confusion resulted in the [mishap pilot] setting a neutral pitch input with the erroneous perception that such an input would hold the attitude observed during the bounce. Instead, the neutral pitch input commanded the aircraft to return to its previously trimmed state.” (Air Force Safety Center, 2007).

Given the human factors problems encountered with the remote operation of a UAV, researchers have investigated the efficacy of a multimodal display (i.e., the presentation of visual, auditory, and tactile information) to compensate for the degradation of sensory information available to a UAV operator (e.g., McCarley & Wickens, 2005). The effective presentation of multimodal information in the non-dominant modalities of hearing and touch can likely enhance the perception of cues in the dominant sensory modality of vision via redundancy and complementary information presentation (Sarter, 2006). For example, when the same information is mapped to multiple modalities, redundancy gains such as faster response times to an incident can be observed (Santangelo, Ho, & Spence, 2008). Also, when complementary information is mapped to two different modalities, there is a synergistic benefit shown (Sarter, 2006). Multimodal displays can serve to substitute for channels that are not available (Sarter, 2006).

Studies have investigated the efficacy of multimodal displays in UAV applications. For example, Calhoun Draper, Ruff, and Fontejon (2002) had participants simultaneously perform a tracking task and a monitoring task to identify system faults. Information in the monitoring task was provided in one of three conditions: tactile, visual, or combined tactile and visual cues. They found that the visual cue required more mental workload than the tactile or the combined tactile and visual cues, and the tactile cue resulted in faster response time and less interference with the concurrent tracking task. Calhoun, Draper, Ruff, Fontejon, and Guilfoos (2003) found that tactile cuing, when presented concurrently with visual and aural alerts, did not aid or degrade performance in a UAV control simulation. However, Calhoun, Fontejon, Draper, Ruff, and Guilfoos (2004) found that a unique redundant alert for critical warnings, whether aural or tactile, helped participants differentiate warning types and improved reaction time to critical events, while performing multiple tasks in a simulated UAV control station. Donmez, Graham, and Cummings (2008) carried out a pilot study that compared tactile cuing for course deviations and arrival times of UAVs in the presence of visual displays, and found that tactile cuing aided in monitoring multiple UAVs. Tactile cues also provide an additional information channel in visual and auditory cluttered environments (Calhoun & Draper, 2006).

Tactile signals can provide force-feedback and substitute for sensory losses (Jones & Sarter, 2008). Hing and Oh (2008) integrated a motion platform with a UAV GCS that provides the remote UAV pilot with motion cues that simulate a manned flight. They argue that the motion will support flight performance by deterring pilots from making excessive maneuvers that the plane cannot handle and help them respond more quickly to flight change (e.g., flying into poor weather). Ruff, Draper, Lu, Poole, and Repperger (2000) investigated the efficacy of haptic displays for alerting UAV operators to the onset of turbulence. To the pilot of a manned aircraft, turbulence is signalled by visual, auditory, and kinaesthetic/haptic information. In contrast, a UAV pilot would experience turbulence by perturbations of the camera image provided by the UAV sensors. They found that haptic information conveyed through the joystick control improved operator's self-rated SA in a simulated UAV approach and landing task. Gunn et al. (2005) reported that response latencies for auditory, force-feedback, and visual cuing were similar in a target acquisition task conducted in a UAV simulator.

The challenge for designers of a GCS that supports a multimodal interface is to present information which maintains the benefits of redundancy (e.g., Santangelo et al., 2008) and synergy (e.g., Sarter, 2006). Designers need to identify when and how they can capitalize on these multimodal benefits that would lead to effective operator decision making. This is a challenging task (Giang et al., 2010). One challenge in offloading the visual modality concerns the effective mapping of information to the auditory and/or tactile modality. For example, information in the form of auditory warnings in the GCS was identified as insufficient or absent (Williams, 2004). To help address this issue, designers adopted a better safe-than-sorry philosophy for the presentation of auditory warnings. This has resulted in false alarm problems in the GCS. For example, in 2005, a CF Sperwer UAV crashed in Kabul, Afghanistan while flying in mountainous terrain. The conclusions of the accident investigation found that a ground proximity warning was ignored by the crew because of frequent false alarms (Canadian Forces, 2005).

The high number of false alarms is a problem because pilots mistrust warnings leading to the "cry wolf" scenario, which accounts for a major factor in aviation accidents (Bliss, 2003). It is important for the operator to know which alarms are expected and which need to be addressed. The next generation alerting systems need to address these issues. In particular, as UAVs become increasingly autonomous (see Section **3.3.1**), UAV operator duties will change from manual control to a supervisory role. Alarm issues such as alarm compliance, alarm reliability, and methods to reduce false alarms will become even more important. Designers of auditory alarms must enhance algorithms to better discriminate truly dangerous conditions from those for which the pilot is (accurately) aware that there is no danger (e.g., terrain contact), while ensuring that the alerts do not become annoying (Wickens, 2003). One approach to help minimize annoyance may be achieved by conveying the appropriate levels of urgency. Different levels of urgency can be conveyed by independently varying the acoustic properties of the sound that include frequency composition, repetition rate, amplitude, and harmonic relation of the frequency components (e.g., Edworthy, Loxley, & Dennis, 1991; Hellier, Edworthy, & Dennis, 1993). For example, whereas a low frequency alarm that repeats slowly is interpreted as having low urgency, a high frequency that repeats quickly is interpreted as having high urgency (Patterson, 1982). Accurate encoding of urgency in auditory alarms through effective use of acoustic parameters may increase detection and reduce the time required to address the alarmed condition without adding to workload (Haas & Casali, 1995; Sorkin, 1988).

Methods for offloading the visual modality in a GCS simulator are being investigated by DRDC Toronto in an ARP, under Partner Group 13QH (Command). This ARP began on April 1, 2009 and has a duration of three years. In support of the JUSTAS project, the objective of the ARP is to evaluate potential benefits of multimodal displays in overcoming limitations imposed by the paucity of cues in a GCS simulator. The team, led by Defence Scientist Mr. Robert Arrabito, comprises science and technology workers from the HSI Section, military members from CFEME, scientists at DRDC Ottawa, as well as industry partners, and academia from the University of Waterloo (Waterloo, Ontario). This project will lead to a greater understanding and potential mitigation of UAV mishaps attributed to human error. The expected outcome will provide knowledge for future UAV acquisitions and/or capability investments, which may enable the CF to develop better strategic policies, procedures and interfaces for UAV control and thus help meet its defence and security commitments for conducting domestic and international C4ISR. This ARP builds on research conducted for the HSI advanced UAV interface design ARP (2003 - 2007) led by Defence Scientist Dr. Ming Hou. Dr. Hou and his colleagues showed that an intelligent adaptive interface (IAI) in a multi-UAV scenario facilitated a significant reduction in workload and increased SA, which led to enhanced decision making (Hou, Kobierski, & Brown, 2007). Design guidance for IAIs is discussed in the next section.

3.3.3 Guidance for Intelligent Adaptive Interfaces (IAIs)

The deployment and control of UAVs generate an enormous amount of data that will become even more complex as more communication channels are engaged between air, sea, and ground for joint operations. As the quantity and variety of those data increase, the workload of UAV operators is likely to increase exponentially, imposing severe constraints on personnel conducting these missions. Feedback from UAV operation reports indicates that there is a need for improvement in the operator interfaces of these emerging systems. This applies to effective UAV control and data management, including converting data into information and efficiently disseminating the information to appropriate users. However, an absence of guidance on designing complex, dynamic, and networked systems (e.g., UAV operator interfaces) presents challenges to the design and specification of such systems to maximize overall human-machine system performance. To address this issue, DRDC Toronto initiated an ARP in 2003 and developed the IAI concept and associated design frameworks. An IAI is an operator interface that dynamically changes the display and/or control characteristics of human-machine systems to adaptively react to external events in real time. A typical IAI is driven by software agents that help to satisfy the decision-making and action requirements of operators under different levels of workload and task complexity by presenting the right information or action sequence proposals, or performing actions, in the right format and at the right time (Hou & Kobierski, 2006a; Hou et al., 2007; Hou & Zhu, 2009).

To investigate the efficacy of the IAI concept and associated frameworks, this three-year ARP was conducted within a multi-UAV control context. The selected scenario involved UAV operations in support of counter-terrorist activities. The IAI was modeled as part of the UAV tactical workstations for a modernized Canadian Maritime Patrol Aircraft CP140. This work was divided into three phases. The first phase involved concept development and performance modeling. The second phase involved the design and development of IAI control stations. The third phase involved the evaluation and validation of the IAI framework.

In the first phase, the IAI concept and associated conceptual framework were developed (Hou, Gauthier, & Banbury, 2007). *Figure 3-1* shows the IAI conceptual framework, which became the guidance for the design of UAV control stations. A generic framework has the four following components, which are common to all developed and developing IAIs:

- Situation Assessment and Support System: this component provides information about the objective state of the aircraft/vehicle/system within the context of a specific mission, and uses a knowledge-based system to provide assistance (e.g., automate tasks) and support to the operator;

- Operator State Assessment: this component provides information about the objective and subjective state of the operator within the context of a specific mission relating to real-time analysis of his or her psychological, physiological and/or behavioural state (e.g., continuous monitoring of workload, inferences about current attentional focus, ongoing cognition, visual and verbal processing load), and intentions using extensive a priori operator knowledge (e.g., models of human cognition, control abilities, and communication);

- Adaptation Engine: this component utilizes the higher-order outputs from Operator State Assessment and Situation Assessment systems, as well as other relevant aircraft/vehicle/system data sources, to maximize the match between aircraft/vehicle/system state, operator state, and the tactical assessments provided by the Situation Assessment system; and

- Operator Machine Interface (OMI): this component provides the means by which the operator interacts with the aircraft/vehicle/system to satisfy mission tasks and goals. This is also the means by which, if applicable, the operator interacts with the intelligent adaptive system (e.g., a tasking interface manager).

The framework is a closed-loop system in which a feedback loop re-samples operator state and situation assessment following the adaptation of the OMI and/or automation. The goal is to adjust the level of adaptation so that optimal operator states (e.g., performance, workload, etc.) are attained and maintained.

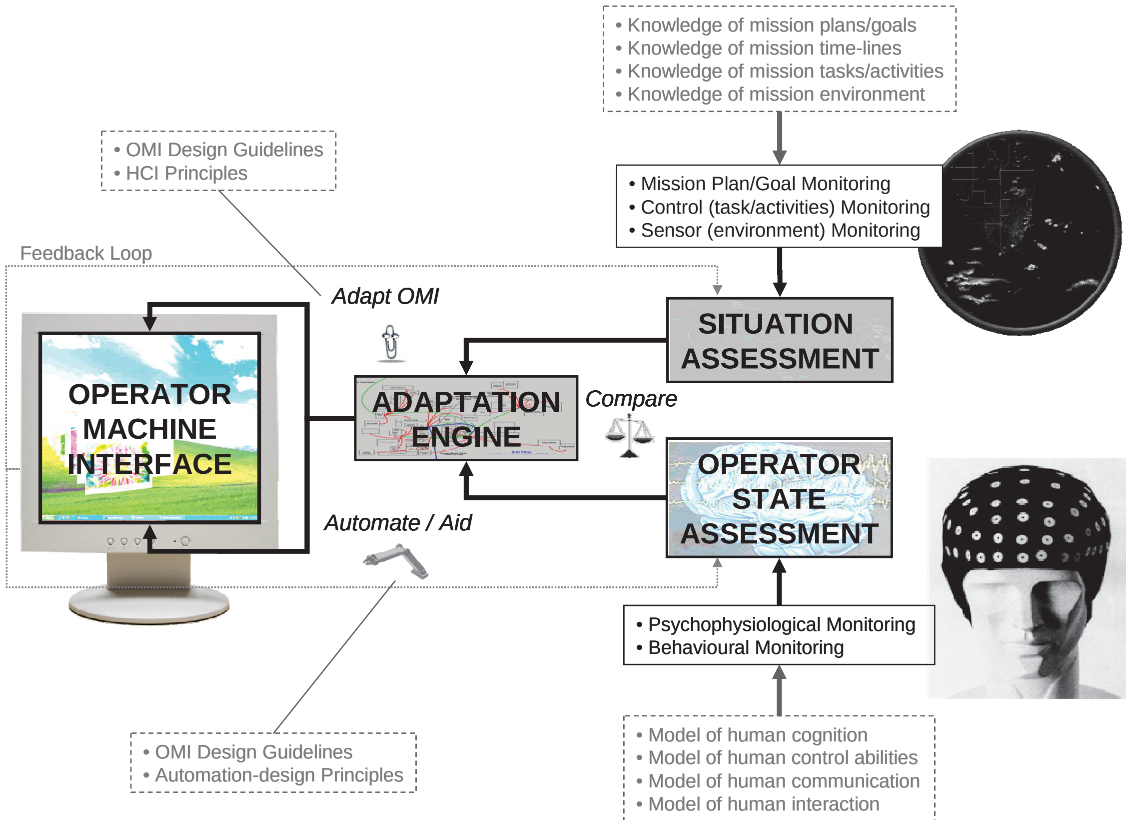


Figure 3-1: Conceptual architecture of IAI systems

Based on the framework, a methodology was produced to analyze UAV operations in a counter-terrorist mission scenario. The scenario reflected a portion of the UAV ALIX at the CF Experimentation Centre (CFEC). The analytical results were used to develop a human-machine task network model that was then implemented in an integrated performance modelling environment (IPME). The model has two modes from which operators may choose when controlling multiple UAVs. One mode assumed that operators used conventional interfaces (i.e., without an IAI) to control multiple UAVs. The other mode assumed that operators used interfaces with IAI automation aiding. The difference between mission activities with and without IAI aiding was reflected in the time to complete critical task sequences and task conflict frequency. The simulation showed that the use of a control interface within an IAI mode permitted operators to complete critical task sequences in reduced time, even under high time pressure (Hou & Kobierski, 2005, 2006a).

The focus in the second phase was on the design and implementation of IAI prototype interfaces that incorporated six system function groups: inter-crew communications, route planning, route following, screen management, data-link monitoring, and UAV sensor selection. A synthetic environment was created which followed the North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 4586 interface software protocol. The experimental environment had three control consoles replicating CP-140 tactical compartment workstations, with a set of displays and controls for each of the UAV crew members: UAV pilot, sensor operator, and tactical navigator *(Figure 3-1)*. The experimental environment also had an integrated video and audio data collection suite to facilitate empirical assessment of IAI concepts.

Human-in-the-loop experiments were conducted in the third phase to examine operator workload and interface adaptability with mock-up UAV control consoles. Eight crews (24 operational CP-140 members) participated in the experiment. Each crew completed a two-day experiment that assessed operator interfaces with and without IAI aiding. The results showed reduced completion time for critical task sequences in the IAI mode. There was also a significant reduction in workload and an improvement in SA (Hou & Kobierski, 2006b; Hou, Kobierski, & Herdman, 2006; Hou et al., 2007).

3.3.4 System Maintenance

Unlike maintenance of a manned aircraft, UAV maintenance requires attention to the entire UAV system including the aircraft, the GCS, the ground data terminal (GDT), and the system network. Specifically, for UAV systems, networked computers are critical to the guidance and control of the aircraft. In particular, little redundancy and low quality components lead to UAVs becoming more prone to in-flight loss link, in addition to mechanical failure and increased dependency on maintenance (**Annex A**).

The above problem was a major concern for the pilots interviewed at Creech USAF Base (**Annex A**), who stated that there are no consistent methods or tools for assessing an in-flight loss link or mechanical failure during an ongoing UAV mission. This lack of framework further increases the operator's lack of confidence in the system. By improving system reliability, operator confidence in the system can increase and system maintenance can also be reduced. Furthermore, a more reliable system (i.e., UAV) offers potentials financial savings (e.g., decrease procurement of spares and attrition of aircraft). In conclusion, supporting and maintaining an optimal system network, its associated software, and improving system reliability are essential for ensuring operational effectiveness.

4 Conclusions

Human factors play an important role in UAV mishaps. Examples of UAV mishaps attributed to human error were provided for the CF and USAF. Various human factors issues were identified in this report for defining future requirements in support of the JUSTAS project. These include organizational influences, operator influences, and HSI issues.

In spite of the fact that UAVs are becoming highly automated, this does not entirely eliminate human input. This has changed the role of humans to supervisory control of the UAVs. Methods need to be developed to maintain UAV operator vigilance and reduce the effects of operator fatigue resulting from shift work schedules to man the GCS around-the-clock. A well-designed human-systems interface can enhance SA, leading to improved operator performance. Multimodal displays may be effective for enhancing user performance in UAV simulation tasks. Future research should investigate these issues to enhance the effectiveness of CF UAV operations.

5 Recommendations for the JUSTAS Project

This section provides short- and long-term recommendations for defining future requirements in support of the JUSTAS project.

5.1 Short-Term

5.1.1 Cognitive Processes for CF CU-170 Heron UAV

Goal: To identify the cognitive processes required to operate the CF CU-170 Heron UAV in order to specify the cognitive processes to operate a MALE UAV.

Task: Perform a CTA on existing CF CU-170 Heron UAV operators to identify skills and knowledge.

5.1.2 Human Factors Analysis on UAV Mishaps

Goal: To support the human factors analysis of current UAV operations in order to minimize UAV mishaps.

Task: Perform a CF HFACS analysis of all MALE UAV mishap data from original accident reports (if possible) to classify personnel cause factors.

5.2 Long-Term

5.2.1 UAV AVO and PO CF MOC

Goal: To develop a UAV AVO and PO MOC in the CF.

Task: Perform research to develop a systematic methodology for selecting UAV operators in the CF.

5.2.2 UAV Human Factors Problems

Goal: To present CF and Allied human factors problems for controlling UAVs that could result in proposing methods to alleviate these problems.

Task: Develop and host an international human factors UAV symposium to discuss personnel cause factors.

5.2.3 Sustained Attention For UAV Operations

Goal: To maintain sustained attention in supervisory control of UAVs that could lead to increased CF operational effectiveness.

Task: Perform research to mitigate the vigilance decrement and operator fatigue associated with shift work.

References

[1] Air Force Safety Center. (2007). Aircraft accident investigation MQ-1B Predator S/N 03-3104. Last accessed on August 9, 2010 from http://usaf.aib.law.af.mil/indexFY07.html.

[2] Arrabito, G. R., Abel, S. M., & Lam, K. (2007). Vigilance decrement in an auditory sonar monitoring task: A research synthesis. *Canadian Acoustics*, *35*, 15-23.

[3] Attar, M. (2005). *Advanced flight control concepts for UAVs*. Paper presented at the UAVNet Regional Workshop.

[4] Bainbridge, L. (1983). Ironies of automation. *Automatica*, *19*, 775-779.

[5] Beck, H. P., McKinney, J. B., Dzindolet, M. T., & Pierce, L. G. (2009). Effects of human-machine competition on intent errors in a target detection task. *Human Factors*, *51*, 477-486.

[6] Bergum, B. O. & Lehr, D. J. (1963). Effects of authoritarianism on vigilance performance. *Journal of Applied Physiology*, *66*, 383-385.

[7] Bliss, J. P. (2003). Investigation of alarm-related accidents and incidents in aviation. *International Journal of Aviation Psychology*, *13*, 249-268.

[8] Bliss, J. P. & Fallon, C. K. (2006). Active warnings: False alarms. In M. S. Wogalter (Ed.), *Handbook of warnings* (pp. 231-244). Mahwah, NJ: Lawrence Erlbaum.

[9] Caldwell, J. A., Mallis, M. M., Caldwell, J. l., Paul, M. A., Miller, J. C., & Neri, D. F. (2009). Fatigue countermeasures in aviation. *Aviation, Space, and Environmental Medicine*, *80*, 29-59.

[10] Calhoun, G. L., & Draper, M. H. (2006). Multi-sensory interfaces from remotely operated vehicles. *Advances in Human Performance and Cognitive Engineering Research*, *7*, 149-163.

[11] Calhoun, G. L., Draper, M. H., Ruff, H. A., & Fontejon, J. V. (2002). Utility of a tactile display for cueing faults. In *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting* (pp. 2143-2148). Baltimore, MD: Human Factors and Ergonomics Society.

[12] Calhoun, G. L., Draper, M. H., Ruff, H. A., Fontejon, J. V., & Guilfoos, B. (2003). Evaluation of tactile alerts for control station operation. In *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting* (pp. 2118-2122). Denver, CO: Human Factors and Ergonomics Society.

[13] Calhoun, G. L., Fontejon, J. V., Draper, M. H., Ruff, H. A., & Guilfoos, B. J. (2004). Tactile versus aural redundant alert cues for UAV control applications. In *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting* (pp. 137-141). New Orleans, LA: Human Factors and Ergonomics Society.

[14] Canadian Forces. (2005). *Flight Safety Investigation Report (FSIR) CU161005*. Ottawa, ON: Directorate of Flight Safety, National Defence Headquarters. Last accessed June 21, 2010 from http://www.airforce.forces.gc.ca/dfs-dsv/nr-sp/index-eng.asp?id=10096.

[15] Chaloux, L. (2008, October). Changes coming for air navigators. *The Maple Leaf*, 10-11. Last accessed September 14, 2010 from http://www.forces.gc.ca/site/commun/ml-fe/article-eng.asp?id=4832.

[16] Colquhoun, W. P. (1959). The effect of a short rest pause on inspection efficiency. *Ergonomics*, *2*, 367-372.

[17] Costa, G. (1999). Fatigue and biological rhythms. In D. J. Garland, J. A. Wise, & V. D. Hopkin (Eds.), *Handbook of Aviation Human Factors* (pp. 235-255). Mahwah, NJ: Lawrence Erlbaum.

[18] Crandall, B., Klein, G., & Hoffman, R. R. (2006). *Working minds: A practitioner's guide to cognitive task analysis*. Cambridge, MA: MIT Press.

[19] Crowley, S. J., Lee, C., Yseng, C. Y., Fogg, L. F., & Eastman, C. I. (2003). Combinations of bright light, scheduled dark, sunglasses, and melatonin to facilitate circadian entrainment to night shift work. *Journal of Biological Rhythms*, *18*, 513-523.

[20] Davies, D. R., & Parasuraman, R. (1982). *The psychology of vigilance*. London, UK: Academic Press.

[21] Defense Science Board (2004). *Defense science board study on unmanned aerial vehicles and uninhabited combat aerial vehicles* (DSB Publication No. 20301-3140). Washington, DC: Office of the Under Secretary of Defense.

[22] Department of National Defence. (2007). *Flight Safety for the Canadian Forces* (Report No. A-GA-135-001/AA-001). Ottawa, ON: Department of National Defence.

[23] Directorate of Flight Safety. D*ND/CF Air Force Uninhabited Aerial Vehicles – Investigation Reports* (November 21, 2003 to January 5, 2009, inclusive). Ottawa, ON. Last accessed on January 31, 2009 from http://www.airforce.forces.gc.ca/dfs-dsv/nr-sp/index-eng.asp?cat=262

[24] Dixon, S. R., & Wickens, C. D. (2006). Automation reliability in unmanned aerial vehicle control: A reliance-compliance model of automation dependence in high workload. *Human Factors*, *48*, 474-486.

[25] Donmez, B., Graham, H., & Cummings, M. (2008). *Assessing the impact of haptic peripheral displays for UAV operators* (Report No. HAL2008-02). Cambridge, MA: MIT Humans and Automation Laboratory. Last accessed June 20, 2010 from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA479798&Location=U2&doc=GetTRDoc.pdf.

[26] Edworthy, J., Loxley, S., & Dennis, I. (1991). Improving auditory warning design: Relationship between warning sound parameters and perceived urgency. *Human Factors*, *33*, 205-231.

[27] Endsley, M. R. (1996). Automation and situation awareness. In R. Parasuraman, & M. Mouloua (Eds.), *Automation and Human Performance* (pp. 163-181). Mahwah, NJ: Lawrence Erlbaum Press.

[28] Endsley, M. R. (1988). Design and evaluation of situation awareness enhancement. In *Proceedings of the Human Factors and Ergonomics Society 32 Annual Meeting* (Vol. 1m, pp. 97-101). Santa Monica, CA: Human Factors and Ergonomics Society.

[29] Endsley, M., & Kiris, E. O. (1995). The out-of-the-loop performance problem and level of control in automation. *Human Factors*, *37*, 381-394.

[30] Fahlstrom, P. G., & Gleason, T. J. (2009). *Introduction to UAV systems* (3rd ed.). Columbia, MD: UAV Systems, Inc.

[31] Farrell, P. S. E., Hubbard, P., & Culligan, I. (2006). *CFEC Project Report on the Alternative Crew Selection Method* (Report No. TM 2006-154). Ottawa, ON: Defence Research and Development Canada – Ottawa.

[32] Farrell, S., & Lewandowsky, S. (2000). A connectionist model of complacency and adaptive recovery under automation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *26*, 395-410.

[33] Finomore, V., Matthews, G., Shaw, T., & Warm, J. (2009). Predicting vigilance: A fresh look at an old problem. *Ergonomics*, *52*, 791-808.

[34] Folkard, S., & Åkerstedt, T. (2004). Trends in the risk of accidents and injuries and their implications for models of fatigue and performance. *Aviation, Space, and Environmental Medicine*, *75*, A161-A167.

[35] Fox, J. G., & Embrey, D. E. (1972). Music: An aid to productivity. *Applied Ergonomics*, *3*, 202-205.

[36] Fraser, D. C. (1953). The relation of an environmental variable to performance in a prolonged visual task. *Quarterly Journal of Experimental Psychology*, *5*, 31-32.

[37] Gawron, V. J., (1998). Human factors issues in the development, evaluation, and operation of uninhabited aerial vehicles. *AUVSI '98: Proceedings of the Association for Unmanned Vehicle Systems International*, 431-438.

[38] Giang, W., Santhakumaran, S., Masnavi, E., Glussich, D., Kline, J., Chui, F., Burns, C., Histon, J., & Zelek, J. (2010). *Multimodal interfaces: Literature review of ecological interface design, multimodal perception and attention, and intelligent adaptive multimodal interfaces* (Report No. CR 2010-051). Toronto, ON: Defence Research and Development Canada – Toronto.

[39] Gorman, J. C., Cooke, N. J., Pedersen, H. K., Winner, J., Andrews, D. H., & Amazeen, P. G. (2006). Changes in team composition after a break: Building adaptive command-and-control teams. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting – 2006* (pp. 487-492). Santa Monica, CA: Human Factors and Ergonomics Society.

[40] Gugerty, L. (2004). Using cognitive task analysis to design multiple synthetic tasks for uninhabited aerial vehicle operation. In L. E. S. Schiflett, E. Salas, & M. Coovert (Eds.), *Scaled worlds: Development, validation and applications* (pp. 240-262). Burlington, VT: Ashgate Publishing.

[41] Gugerty, L., DeBloom, D., Walker, R., & Burns, J. (1999). Developing a simulated uninhabited air vehicle (UAV) task based on cognitive task analysis: task analysis results and preliminary simulator performance data. In *Proceedings of the Human Factors and Ergonomics Society 43rd Annual Meeting* (pp. 86-90). Houston, TX: Human Factors and Ergonomics Society.

[42] Gunn, D. V., Warm, J. S., Nelson, W. T., Bolia, R. S., Schumsky, D. A., & Corcoran, K. J. (2005). Target acquisition with UAVs: Vigilance displays and advanced cuing interfaces. *Human Factors*, *47*, 488-497.

[43] Haas, E. C., & Casali, J. G. (1995). Perceived urgency of and response to multi-tone and frequency-modulated warning signals in broadband noise. *Ergonomics*, *38*, 2313-2326.

[44] Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock, & N. Meshkati (Eds.), *Human mental workload* (pp. 139-183). Amsterdam, Holland: North-Holland.

[45] Hawley, J. K., Mares, A. L., & Giammanco, C. A. (2005). *The Human Side of Automation: Lessons for Air Defense Command and Control*. Aberdeen Proving Ground, MD: Army Research Laboratory.

[46] Hellier, E. J., Edworthy, J., & Dennis, I. (1993). Improving auditory warning design: Quantifying and predicting the effects of different warning parameters on perceived urgency. *Human Factors*, *35*, 693-706.

[47] Helmreich, R. L., Merritt, A. C., & Wilhelm, J. A. (1999). The evolution of crew resource management training in commercial aviation. *International Journal of Aviation Psychology*, *9*, 19-32.

[48] Helton, W. S., Hollander, T. D., Warm, J. S., Matthews, G., Dember, W. N., Wallaart, M., Beauchamp, G., Parasuraman, R., & Hancock, P. A. (2005). Signal regularity and the mindlessness model of vigilance. *British Journal of Psychology*, *96*, 249-261.

[49] Herz, R. P. (2008). *Assessing the influence of human factors and experience on predator mishaps*. Unpublished doctoral dissertation, Northcentral University, AZ.

[50] Hing, J., & Oh, P. Y. (2008). Integrating motion platforms with unmanned aerial vehicles to improve control, train pilots and minimize accidents. In *Proceedings of the ASME 2008 International Design Engineering Technical Conference and Computers, and Information in Engineering Conference* (pp. 867-875). Brooklyn, NY: ACME.

[51] Hodges, J. (September 1, 2009). ‘Smarter’ UAVs could help avoid human error during landings. *C4ISR Journal*. Last accessed on July 13, 2010 from http://www.c4isrjournal.com/story.php?F=4217657.

[52] Hopcroft, R., Burchat, E., & Vince, J. (2006). *Unmanned aerial vehicles for maritime patrol: Human factors issues* (Report No. DSTO-GD-0463). Victoria, Australia: Defence Science and Technology Organisation.

[53] Hou, M., Gauthier, M. S., & Banbury, S. (2007). Development of a generic design framework for intelligent adaptive systems. In J. Jacko (Ed.), *12th International Conference, HCI International 2007: Part 3. Human-computer interaction* (pp. 313-320). Berlin, Germany: Springer-Verlag.

[54] Hou, M., & Kobierski, R. D. (2006a) Operational Analysis and Performance Modeling for the Control of Multiple Uninhabited Aerial Vehicles from an Airborne Platform. *Advances in Human Performance and Cognitive Engineering Research*, *7*, 267-282.

[55] Hou, M., & Kobierski, R. D. (2006b). *Intelligent Adaptive Interface: Summary report on design, development, and evaluation of intelligent adaptive interfaces for the control of multiple UAVs from an airborne platform.* (Report No. TR 2006-292). Defence Research and Development Canada – Toronto.

[56] Hou, M., & Kobierski, R. D. (2005). Performance modeling of agent-aided operator-interface interaction for the control of multiple UAVs. *Systems, Man and Cybernetics, 2005 IEEE International Conference*: Vol. 3. (pp. 2463-2468). Piscataway, NJ: Institute of Electrical and Electronics Engineers.

[57] Hou, M., Kobierski, R. D., & Brown, M. (2007). Intelligent adaptive interfaces for the control of multiple UAVs. *Journal of Cognitive Engineering and Decision Making*, *1*, 327-362.

[58] Hou, M., Kobierski, R. D., & Herdman, C. M. (2006, October). Design and evaluation of intelligent adaptive operator interfaces for the control of multiple UAVs. In R. Taylor & H. Ruck (Chairs), *Human factors of uninhabited military vehicles as force multipliers.* Presented at NATO RTO Human Factors and Medicine Panel (HFM) 135 Symposium, Biarritz, France.

[59] Hou, M., & Zhu, H. (2009, October). Intelligent adaptive interface: A design tool for enhancing human-machine system performance. In R. Foster (Chair), *Human performance enhancement: science, technology, and ethics.* Presented at NATO RTO Human Factors and Medicine Panel (HFM) 181 Symposium, Sofia, Bulgaria.

[60] Hoyle, C. (March 3, 2010). USAF, RAF share experiences of fast-track UAV training. *Flight International*. Last accessed March 21, 2010 from http://www.flightglobal.com/articles/2010/03/03/339009/usaf-raf-share-experiences-of-fast-track-uav-training.html.

[61] Jones, L. A., & Sarter, N. B. (2008). Tactile displays: Guidance for their design and application. *Human Factors*, *50*, 90-111.

[62] Klein, G., & Militello, L. (2001). Some guidelines for conducting a cognitive task analysis. In E. Salas, C. A. Bowers, N. Cooke, J.E. Driskell, & D. Stone (Eds.), *Advances in human performance and cognitive engineering research* (pp. 163-199). Kidlington, Oxford: Elsevier Science Ltd.

[63] Krueger, G. P. (1989). Sustained work, fatigue, sleep loss and performance: A review of the issues. *Work & Stress*, *3*, 129-141.

[64] Lee, J. D. (2008). Review of a Pivotal Human Factors Article: "Humans and Automation: Use, Misuse, Disuse, and Abuse". *Human Factors, 50*, 404-410.

[65] Linegang, M. P., Stoner, H. A., Patterson, M. J., Seppelt, B. D., Hoffman, J. D., Crittendon, Z. B., & Lee, J. D. (2006). Human-automation collaboration in dynamic mission planning: A challenge requiring an ecological approach. In *Proceedings of the Human Factors and Ergonomics Society 50th Annual Meeting* (pp. 2482-2486). San Francisco, CA: Human Factors and Ergonomics Society.

[66] Mackworth, N. H. (1950). *Researches on the measurement of human performance* (Special Report Series No. 268). London, UK: Medical Research Council, H. M. Stationery Office.

[67] Macmillan, N. A., & Creelman, C. D. (1991). *Detection theory: A user's guide*. New York, NY: Cambridge University Press.

[68] Manning, S. D., Rash, C. E., LeDuc, P. A., Noback, R. K., & McKeon, J. (2004). *The role of human causal factors in U.S. army unmanned aerial vehicle accidents* (USAARL Report No. 2004-11). Fort Rucker, AL: U.S. Army Safety Center, U.S. Army Aviation Branch Safety Office, U.S. Army Aeromedical Research Laboratory.

[69] Matthews, G., Davies, D. R., Westerman, S. J., & Stammers, R. (2000). *Human performance: Cognition, stress and individual differences*. Hove, UK: Psychology press.

[70] McCarley, J. S., & Wickens, C. D. (2005). *Human factors implications of UAVs in the national airspace* (Technical Report no. AHFD-05-05/FAA-05-01). Savoy, IL: University of Illinois at Urbana-Champaign, Aviation Human factors Division.

[71] McCormack, D. (1959). Performance in vigilance task with and without knowledge of results. *Canadian Journal of Psychology*, *13*, 68-71.

[72] Molloy, R., & Parasuraman, R. (1996). Monitoring an automated system for a single failure: Vigilance and task complexity effects. *Human Factors*, *38*, 311-322.

[73] Moray, N. (2000). Are observers ever really complacent when monitoring automated systems? In *Proceedings of the 14th Triennial Congress of the International Ergonomics Association and the 44th Annual Meeting of the Human Factors and Ergonomics Society* (Vol 1, pp. 592-595). Santa Monica, CA: Human Factors and Ergonomics Society.

[74] Mouloua, M., Gilson, R., Daskarolis-Kring, E., Kring, J., & Hancock, P. (2001). Ergonomics of UAV/UCAV Mission Success: Considerations for data link, control, and display issues. In *Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting* (pp. 144-148). Minneapolis, MN: Human Factors and Ergonomics Society.

[75] Muecke, S. (2005). Effect of rotating night shifts: Literature review. *Journal of Advanced Nursing*, *50*, 433-439.

[76] Newton, S. J., Regush, M. M., Comeau, P., Van Bavel, G., Bowes, R. K., & Shurson, A. M. (2005). *Experimental Military Report IISRA 2004-01 Atlantic Littoral ISR Experiment (ALIX) for Allied Distribution.* Ottawa, ON: Canadian Forces Experimentation Centre.

[77] Nullmeyer, R. T., Herz, R., Montijo, G. A., & Leonik, R. (2007). Birds of prey: Training solutions to human factors issues. *Interservice/Industry Training, Simulation, and Education Conference* (paper number 7133). Orlando, FL.

[78] Parasuraman, R., Molloy, R., Mouloua, M., & Hilburn, B. (1996). Monitoring of automated systems. In R. Parasuraman, & M. Mouloua (Eds.), *Automation and Human Performance* (pp. 91-115). Mahwah, NJ: Lawrence Erlbaum Press.

[79] Parasuraman, R., Molloy, R., & Singh, I. L. (1993). Performance consequences of automation-induced complacency. *The International Journal of Aviation Psychology*, *3*, 1-23.

[80] Parasuraman, R., & Riley, V. (1997). Humans and automation: Use, misuse, disuse, abuse. *Human Factors*, *39*, 230-253.

[81] Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *30*, 286-297.

[82] Parasuraman, R., Warm, J., & Dember, W. (1987). Overview paper: Vigilance: Taxonomy and utility. In L. Mark, J. Warm, & R. Huston (Eds.), *Ergonomics and human factors: recent research* (pp. 11-32). New York, NY: Springer-Verlag.

[83] Patterson, R. D. (1982). *Guidelines for auditory warning systems on civil aircraft* (Report 82017). London, UK: Civil Aviation Authority.

[84] Paul, M. A., Gray, G., Kenny, G., & Pigeau, R. A. (2003). Impact of melatonin, zaleplon, zopiclone, and temazepam on psychomotor performance. *Aviation, Space and Environmental Medicine*, *74*, 1263-1270.

[85] Paul, M. A., Miller, J. C., Gray, G. W., Love, R. J., Lieberman, H. R., & Arendt, J. (2009a). Melatonin treatment for eastward and westward travel preparation. *Psychopharmacology*, *208*, 377-386.

[86] Paul, M. A., Miller, J. C., Love, R. J., Lieberman, H., Blazeski, S., & Arendt, J. (2009b). Timing light treatment for eastward and westward travel preparation. *Chronobiology International*, *26*, 867-890.

[87] Pederson, H. K., Cooke, N. J., Pringle, H. L., & Connor, O. (2006). UAV human factors: Operator perspectives. In H. L. Pringle, H. K. Pedersen, O. Connor, & E. Salas (Eds.), *Human factors of remotely operated vehicles* (pp. 21-36). Amsterdam, The Netherlands: Elsevier.

[88] Penn, P. E., & Bootzin, R. R. (1990). Behavioural techniques for enhancing alertness and performance in shift work. *Work & Stress*, *4*, 213-226.

[89] Pigeau, R. A., Angus, R. G., O'Neill, P., & Mack, I. (1995). Vigilance latencies to aircraft detection among NORAD surveillance operators. *Human Factors*, *37*, 622-634.

[90] Pope, A. T., & Bogart, E. H. (1992). Identification of hazardous awareness states in monitoring environments. *Journal of Aerospace*, *101*, 448-457.

[91] Rasmussen, J. (1998). *Ecological interface design for complex systems: An example: SEAD-UAV systems* (USAF Report No. AFRL-HE-WP-TR-1999-0011). Fairborn, Oh: Wright-Patterson Air Force Research Laboratory.

[92] Ruff, H. A., Draper, M. H., Lu, L. G., Poole, M. R., & Repperger, D. W. (2000). Haptic feedback as a supplemental method of alerting UAV operators to the onset of turbulence. In *Proceedings of the IEA 2000 / HFES 2000 Congress* (pp. 3.41-3.44). San Diego, CA: International Ergonomics Society and Human Factors and Ergonomics Society.

[93] Santangelo, V., Ho, C., & Spence, C. (2008). Capturing spatial attention with multisensory cues. *Psychonomic Bulletin and Review*, *15*, 398-403.

[94] Sarter, N. B. (2006). Multimodal information presentation: Design guidance and research challenges. *Journal of Industrial Ergonomics*, *36*, 439-445.

[95] Schreiber, B. T., Lyon, D. R., Martin, E. L., & Confer, H. A. (2002). *Impact of prior flight experience on learning Predator UAV operator skills* (USAF Technical Report No. AFRLHE- AZ-TR-2002-0026). Mesa, AZ: Air Force Research Laboratory, Human Effectiveness Directorate Warfighter Training Research Division.

[96] See, J. E., Howe, S. R., Warm, J. S., & Dember, W. N. (1995). Meta-analysis of the sensitivity decrement in vigilance. *Psychological Bulletin*, *117*, 230-249.

[97] Sheridan, T. B. (1987). Supervisory control. In G. Salvendy (Ed.), *Handbook of Human Factors* (pp. 1243-1268). New York, NY: Wiley.

[98] Skitka, L. J., Mosier, K. L., & Burdick, M. D. (1999). Does automation bias decision-making? *International Journal of Human-Computer Studies*, *51*, 991-1006.

[99] Sorkin, R. D. (1988). Why are people turning off our alarms? *Journal of the Acoustical Society of America*, *84*, 1107-1108.

[100] St. John, M., & Risser, M. R. (2009). Sustaining vigilance by activating a secondary task when inattention is detected. In *Proceedings of the Human Factors and Ergonomics Society 53rd Annual Meeting* (pp. 155-159). San Diego, CA: Human Factors and Ergonomics Society.

[101] Thackray, R. I. (1981). The stress of boredom and monotony: A consideration of the evidence. *Psychosomatic Medicine*, *43*, 165-176.

[102] Thackray, R. I., Bailey, J. P., & Touchstone, R. M. (1979). The effect of increased monitoring load on vigilance performance using a simulated radar display. *Ergonomics*, *22*, 529-539.

[103] Thompson, W., Lopez, N., Hickey, P., DaLuz, C., Caldwell, J. L., & Tvaryanas, A. P. (2006). *Effects of shift work and sustained operations: Operator performance in remotely piloted aircraft (OP-REPAIR)* (Report No. HSW-PE-BR-TR-2006–0001). Brooks City-Base, TX: United States Air Force, 311th Human Systems Wing.

[104] Tvaryanas, A. P. (2006). Human systems integration in remotely piloted aircraft operations. *Aviation, Space, and Environmental Medicine*, *77*, 1278-1282.

[105] Tvaryanas, A. P., Platte, W., Swigart, C., Colebank, J., & Miller, N. L. (2008). *A resurvey of shift work-related fatigue in MQ-1 predator unmanned aircraft system crewmembers* (Report No. NPS OR-08-001). Monterrey, CA: Navy Postgraduate School.

[106] Tvaryanas, A. P., & Thompson, W. T. (2006). Fatigue in military aviation shift workers: survey results for selected occupational groups. *Aviation, Space, and Environmental Medicine*, *77*, 1166-1170.

[107] Tvaryanas, A. P., Thompson, B. T., & Constable, S. H. (2005). *U.S. military unmanned aerial vehicle mishaps: assessment of the role of human factors using HFACS* (Report No. HSW-PE-BR-TR-2005-001). San Antonio, TX: Terra Health Incorporated.

[108] United States Air Force. *Class A Aerospace Mishaps* (Fiscal Year 2000 to Fiscal Year 2008, inclusive). Albuquerque, NM. Last accessed on January 31, 2009 from http://usaf.aib.law.af.mil.

[109] van Blyenburgh, P. (1999). UAVs – Current situation and considerations for the way forward. *Paper presented at the RTO AVT Course on "Development and Operation of UAVs for Military and Civil Applications"*. Rhode-Saint-Gense, Belgium: RTO EN-9.

[110] van Erp, J. B. F., & van Breda, L. (1999). *Human factors issues and advanced interface design in maritime unmanned aerial vehicles: A project overview* (TNO Report No. TM-99-AOO4). Soesterberg, the Netherlands: TNO Human Factors Research Institute.

[111] Warm, J. S. (1993). Vigilance and target detection. In B. M. Huey, & C. D. Wickens (Eds.), *Workload transition: Implications for individual and team performance* (pp. 139-170). Washington, DC: National Academy Press.

[112] Warm, J. S. (1984). An introduction to vigilance. In J. S. Warm (Ed.), *Sustained Attention in Human Performance* (pp. 1-14). Toronto, ON: John Wiley & Sons.

[113] Warm, J. S., & Dember, W. N. (1998). Tests of Vigilance Taxonomy. In R. R. Hoffman, M. F. Sherrick, & J. S. Warm (Eds.), *Viewing psychology as a whole: The integrative science of William N. Dember* (pp. 87-112). Washington, DC: APA.

[114] Warm, J. S., Dember, W. N., & Hancock, P. A. (1996). Vigilance and Workload in Automated Systems. In R. Parasuraman & M. Mouloua (Eds.), *Automation and human performance: Theory and applications* (pp. 183-200). Mahwah, NJ: Lawrence Erlbaum Associates.

[115] Warm, J. S., & Jerison, H. J. (1984). The psychophysics of vigilance. In J. S. Warm (Ed.), *Sustained attention in human performance* (pp. 15-59). Toronto, ON: John Wiley & Sons.

[116] Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance requires hard mental work and is stressful. *Human Factors, 50*, 433-441.

[117] Weeks, J. L. (2000). *Unmanned aerial vehicle operator qualifications* (Report No. AFRL-HE-AZ-TR-2000-0002). Mesa, AZ: Air Force Research Laboratory.

[118] Wickens, C. D. (2003). Aviation displays. In P. S. Tsang, & M. A. Vidulich (Eds.), *Principles and practice of aviation psychology* (pp. 147-200). Mahwah, NJ: Lawrence Erlbaum Associates.

[119] Wickens, C. D., & Hollands, J. G. (2000). *Engineering psychology and human performance*. Upper Saddle River, NJ: Prentice Hall.

[120] Williams, K. W. (2006). *Human factors implications of unmanned aircraft accidents: Flight control problems* (Report No. DOT/FAA/AM-06/8). Oklahoma City, OK: FAA Civil Aerospace Medical Institute.

[121] Williams, K. W. (2004). *A summary of unmanned aircraft accident/incident data: Human factors implications* (Report No. DOT/FAA/AM-04/24). Oklahoma City, OK: FAA Civil Aerospace Medical Institute.

[122] Woods, D. D. (1996). Decomposing automation: Apparent simplicity, real complexity. In R. Parasuraman, & M. Mouloua (Eds.), *Automation and Human Performance* (pp. 3-17). Mahwah, NJ: Lawrence Erlbaum Press.

Annex A Trip Report of Creech AFB and Kirtland AFB Visit

A.1 Introduction

A.1.1 Background

The understanding of UAV operations is greatly enhanced through discussion of the experiences of individuals operating UAV aircraft in combat. The Canadian Forces (CF) experience with medium altitude, long-endurance (MALE) uninhabited aerial vehicles (UAV) combat operations is very limited so it was decided that an attempt would be made to gather this information from an allied organization with greater experience – the United States Air Force (USAF). The USAF has been performing combat operations using the General Atomics built MQ-1 Predator UAV since approximately 1995, and the larger MQ-9 Reaper UAV since 2007. As well, the USAF has moved toward arming their platforms, something that the CF will start in the later stages of the Joint Unmanned Aerial Vehicle Surveillance and Target Acquisition System (JUSTAS) project. Consequently, the USAF has built up a large body of first-hand knowledge and experience on the human factors challenges associated with UAV combat operations. It was decided that as much of this information as possible should be gathered in support of the JUSTAS project, and a fact-finding visit to the USAF was organized.

Two Human Factors specialists from Canadian Forces Environmental Medicine Establishment (CFEME) visited two USAF organizations that are either associated with UAV operations directly, or are part of the USAF flight safety program. One specialist was an Aerospace Engineering Officer with a Masters in Human Factors (Capt Annie Lambert), and the other specialist was a Bio Science Officer with a Masters in Human Factors (Capt Mark Rutley). The organizations chosen for this visit were the 432nd Wing and 432nd Air Expeditionary Wing (AEW) located at Creech Air Force Base (AFB) in Indian Springs, Nevada, and the USAF Safety Center located at Kirtland AFB in Albuquerque, New Mexico. The visits occurred between 2 February 2009 and 7 February 2009, with one full day spent at each location. The goal of these visits was to identify and document human factors challenges faced by the USAF while conducting UAV combat operations using a MALE UAV (the MQ-1 Predator and the MQ-9 Reaper).

A.1.2 Purpose and Scope

The purpose and scope of this annex is to describe a fact finding trip conducted by two CF human factors Air Accident Investigators to Creech AFB and Kirtland AFB which specialize in UAV operations or the safety of UAV operations. This annex will detail the visits and the information gathered.

A.2 Creech AFB

Creech AFB was visited on 3 February 2009. It is located in Indian Springs, Nevada, and is home to both the 432nd Wing and 432nd Air Expeditionary Wing (AEW). The 432nd Wing, and 432nd AEW, are part of the organization of the U.S. Air Combat Commands 12th Air Force. They serve as both a training facility for new MQ-1 Predator and MQ-9 Reaper airmen, and as a combat-ready force flying MQ-1 and MQ-9 aircraft in support of American and Coalition forces around the world. During the course of the tour, the following facilities were visited:

- The 432nd Aircraft Maintenance Squadron hangar,
- The 432nd training and simulation facility, and
- The 432nd AEW itself, including an operating MQ-1 Ground Control Station (GCS).

During this visit, unstructured interviews were conducted with the following individuals (names withheld):

1. a USAF physiologist specializing in flight safety,
2. a maintenance officer,
3. a MQ-1 pilot training officer,
4. a MQ-1 pilot,
5. a MQ-1 sensor operator, and
6. a CF liaison officer stationed at 432nd AEW.

Structured interviews were conducted with the following individuals (names withheld):

1. two MQ-1 pilots, and
2. two MQ-1 sensor operators.

An unstructured interview is defined here as an informal interaction with individuals encountered during the tours of the Creech facilities that were available to answer questions. A structured interview is defined here as a more formal interview process in which discussion with a UAV crew (pilot and sensor operator) took place in a meeting room concerning their experiences operating the UAV. Note that the individuals interviewed volunteered their opinion of the challenges they encountered in conducting UAV operations, and that these personal opinions may not reflect the overall state of UAV operations in the USAF.

A.2.1 Organizational Influences

Organizational influences refer to system-wide human factors prevalent to the Air Force. These factors include organizational culture, standard operating procedures, and leadership, and define the environment in which individuals perform their daily tasks. The remainder of this section discusses organizational influences observed at Creech AFB.

The USAF operates the MQ-1 and MQ-9 UAVs under what is termed “split operations”. This means that each UAV is controlled by two crews. The “mission crew” is located in the Continental U.S. (CONUS) and is responsible for controlling the weapons system for the entire mission, with the exclusion of take-off and landing. The “landing crew” is pushed forward, and located in theatre on the airbase that has been designated as the logistical support center for the UAV. The landing crew is responsible for all take-offs and landings, and transits up to and down from an altitude of 5000 feet of all UAVs supported by that air base.

MQ-1s are crewed by a pilot and a sensor operator. The pilot is usually a USAF-trained manned flight pilot that has either been designated to fly UAVs, or has a medical category that restricts their ability to conduct manned flight operations. Most have a tactical fighter background. The sensor operator is usually a non-commissioned member who has been specifically trained for that role. Additional sensor operators can be part of the crew, depending on if there are any extra sensor suites attached to the hard points of the airframe (e.g. side aperture radar). The operating crews are supported by up to 10 image analysts or intelligence specialists located in another portion of the facility. Mission crew composition is not fixed, and pilots or sensor operators can be interchanged depending on the shift schedule, crew availability and operations. Consequently there are no static operator “teams”.

MQ-1 mission crews are assigned to one of three shifts per day. The shifts are structured such that personnel have approximately 1 hour of administrative duty, 3 hours of flying duty, 2 hours of non-flying duties, 3 more hours of flying duties, and then are considered off duty. The shifts are labelled “mornings”, “mids” and “nights”. Personnel rotate through the shifts on a monthly basis.

To pursue two lines of tasking (i.e., conduct missions in two separate areas of interest (AOI)), at least nine complete mission crews are required. Anything less than that necessitates increased workload on the part of the operators.

Mission crews usually control a single UAV. However, the USAF has been experimenting with a single team of operators controlling multiple UAVs in several AOI's. This generally consists of crews switching the GCS from one UAV telemetry link to another telemetry link to monitor that UAV’s systems, and perform any course or sensor suite corrections as required.

Although the squadron has a well-defined internal chain of command, the external chain of command is not as clear. Mission crews report that they are often directly contacted from other commands via the telephone in the GCS, requesting that they perform a particular action with their UAV. Examples of such requests include engaging targets, redirecting the sensor suite to observe another target, or redirecting the entire UAV to overfly another area. UAV operators reported frustration due to requests for drastically modifying the goal/objective of an ongoing mission through poorly defined chains of command.

A.2.2 Human-System Integration Issues

The MQ-1 GCS comprises two operator stations: one for the pilot and one for the sensor operator (see Figure B-1). They are generally housed in an air-conditioned room that has a mild to moderate level of ambient noise, depending on the level of air-conditioning and the number of computer cooling fans. There are several GCS variants, and although all have the same number and type of controls there are differences in control layout from one GCS variant to the next. The two GCS examined during this visit were the training variant and a “mobile” variant that was designed to be easily packed and shipped.

Both operators are seated in leather-covered deeply cushioned chairs that are capable of moving up and down and forward and back in relation to a shelf-like main console. Both operator stations are morphologically similar in control layout. They are equipped with rudder pedals which are positioned well below the main console. There is a throttle quadrant on the left of the main console consisting of a large power lever with a smaller red lever next to it. The larger power lever is equipped with several unlabeled buttons, all of which have the same tactile feel and function. On the right of the console is a flight stick, equipped with a trigger button, and several of the same unlabeled buttons as the throttle. In between the throttle and flight stick is a black keyboard. To the right of the flight stick is either a mouse or trackball. There is a landing gear lever located on the front surface of the main control panel just in front of the throttle, although it has been reported that this position is not fixed for all GCS variants.

Each station has four screens. Two of the screens are small, angled and located directly behind the flight controls. They are called the Variable Information Terminals (VITs). These are menu driven displays containing textual information representing the various aircraft systems. There is an approximately 4 cm by 10 cm blue field that serves as a combined system warning and status display that operates similar to a chat room screen, whereby warnings or statements of system status appear at the bottom of the screen and are moved upwards with each successive appearance of a new warning or statement of system status. The VITs are controlled using the keyboard, such that each “page” of information can be selected using one of the function keys. Note that in the mobile GCS, the VITs are rendered on the Heads Up Display (HUD) (see Figure B-1) instead of having their own designated displays.

The other two screens are the same size (approximately 50 cm by 50 cm) and consist of the Main display and the HUD. The Main display is directly in front of the operator controls. For the pilot, this display can show either the view generated by the nose camera, or the view generated by the sensor ball. Overlaid onto this camera view is the slightly modified symbology from a standard F-16 HUD (see Figure B-2). The pilots interviewed stated that all the information required to fly the aircraft was present on this display. For the sensor operator, the view is directly from the sensor ball. Overlaid on this view is textual information concerning the sensor ball’s settings, such as mode, light gain, bearing, azimuth, etc. See Figure B-3 for an image of the sensor ball display and description of the symbology.

Above the main display is the HUD. This display consists of a moving map of the AOI, the footprint view from the nose camera, the footprint view of the sensor ball (both as a yellow hash overlay on the map), the direction of aircraft flight, and all waypoints programmed into the auto pilot. This display is used by the pilot to program and update the aircraft's waypoints. This display also controls select aircraft systems, such as weaponry or other hardpoint-mounted sensors. Interaction with this display is performed by mouse and keyboard. Almost all items are controlled through a selection of drop down menus, including maintenance of the weapons system.

The GCS could be equipped with up to four other displays. Almost all of them have a FalconView moving map display located somewhere between the two operator stations. To the left of the sensor operator and the right of the pilot is another display and keyboard for the m internet relay chat (mIRC) system. A final screen can be used to display overall system health of the various computers that drive the GCS.

Control of various aircraft systems is done through a "challenge-response" procedure. For example, to turn off the engine, the pilot must press the engine off button located on the throttle. This prompts a blue-coloured message on the main display requesting confirmation for the command to turn off the engine. Confirmation is performed by activating the flight stick trigger. Other commands operate in a similar manner, such as turning on and off aircraft systems, manipulating aircraft trim, raising and lowering landing gear, and releasing weapons. Mission crews reported that the similarity in button tactile response to confirm the various commands results in frequent action errors. For example, an anecdote was provided where a pilot-trainee practicing a weapons release inadvertently turned off the aircraft's engine because the weapon release button and the engine off button were co-located on the throttle, and confirmation of each command was the same.

The GCS is equipped with two non-verbal auditory alarms, both having the same pitch. One alarm is an intermittent tone and the other alarm is a continuous tone. It is unclear which conditions trigger one alarm over another. The alarm is often accompanied by a message on the main display. Cancelling the alarm appears to be done through various methods, such as activating the flight stick trigger, or through mouse and keyboard control of the HUD. The alarms do not occur frequently.

Mission crews operate the aircraft largely by autopilot. There are three autopilot modes: heading hold, airspeed hold and altitude hold. As well, the GCS is capable of flying the UAV through a series of waypoints. Weapons delivery is performed manually. Landing crews fly the aircraft manually all the time.

Mission crews experience substantial lag as a result of long distance, satellite-mediated, radio communications. This lag is usually up to 2 seconds but may be longer. There is usually no lag for landing crews because communications are predominantly facilitated through direct line-of-sight radio transmissions.

There is no precise height above ground instrument available to the pilots. Consequently, each pilot develops their own technique when flaring the aircraft for landing. One pilot stated that he flares only when he can “see runway details” such as pebbles or stones in the camera image. Others stated that they flare when the camera image approximates that of a “standard sight picture”. Still others flare via timing alone. This lack of fidelity to sense height over ground results in a lot of pilot induced oscillation during the landing phase, and subsequent loss of control and damage to the landing gear, sensor ball or other airframe components.

During the visit to the 432nd operational MQ-1 GCS, a technical malfunction developed while on the down wind leg for landing. The malfunction involved a mismatch of approximately two degrees between the two UAV autopilots. The result was that the artificial horizon line of the main display did not align itself with the real horizon line, but rather was canted at an angle two degrees off. After approximately five minutes of discussion, the pilot and sensor operator resolved the problem. However, the agreed-upon solution was to simply fly the aircraft relative to the visible real horizon and ignore the artificial horizon. This solution would be less than ideal in a situation where the horizon was occluded due to sand, fog or clouds.

A.2.3 Situation Awareness

MQ-1 pilots know when the aircraft has deviated from course only when the aircraft is no longer following the line from one waypoint to another, as seen on the HUD moving map.

A “turn and slip” indicator was added to the sensor suite by placing a piece of string on the nose of the aircraft within view of the nose camera. A pitch-angle indicator was added in the same fashion. This consists of a small, brightly coloured wing, attached to the front of the airframe within view of the nose camera.

Turbulence is sensed through shaking of the nose camera image (the sensor ball is stabilized), and a gravitational (g) metre display which gives g-reading in the z-axis, in the lower right hand corner of the main display. The sensor ball is often used to ensure that a weapon release has actually occurred.

A.2.4 Crew Coordination

MQ-1 mission crews and landing crews use Davidson-Clarke half headsets. This provides them with external radio communications. As well, having one ear uncovered allows them to communicate between themselves without requiring an intercom link. However, this also exposes one ear to environmental noise, such as the drone of air-conditioning fans and computer cooling equipment.

A control handover sequence occurs between mission crews and take-off/landing crews when the UAV reaches an altitude of approximately 5000 feet. The sequence involves deliberately losing satellite link to the UAV such that the next GCS to control the aircraft can search and acquire it. Occasionally, UAVs are lost because of an inability to reacquire after deliberately losing link.

Handover between mission crews occurs frequently throughout a typical 16-hour UAV mission. The outgoing mission crew will provide the incoming mission crew with a standardized mission brief, including such items as weather, conflicting traffic, and the status of the UAV. The incoming crew will then take their place at the controls, and readjust the GCS settings according to their own preferences. Examples of setting preferences include adjusting control stick "dead space", the kind of information that is displayed on what screen, sensitivity of alarms, sensor ball settings, etc. There are no standard settings for all UAV operators.

The checklist for the MQ-1 was created from a computer system management perspective (i.e. key presses) and thus does not resemble a standard manned aviation checklist. There are several unofficial "checklists" for conducting mission crew hand-over briefs. This creates problems because one operator's checklist may not be similar to another's. Lack of standardization can result in missing information or miscommunication between operators.

A.2.5 System Maintenance

Because of the "disposable" nature of the design of the MQ-1, there is very little redundancy or aeronautical airworthiness built in. One anecdote described how, due to airframe vibrations, the sensor providing feedback on engine RPM was shaken loose, resulting in the loss of that data stream and the near crash of the airframe. UAV operators stated that mechanical malfunctions of the UAV occur frequently. In the event that they do occur, it is difficult for the pilot to identify and troubleshoot the problem. Frequently, operators call the civilian maintenance company to trouble shoot the UAV while it is in the air.

A.3 Kirtland AFB

Kirtland AFB was visited on 6 February 2009. It is located southeast of Albuquerque, New Mexico between the Sandia and Manzano mountain ranges. It is a large, sprawling airbase that is home to several air wings, various USAF and U.S. government test, research and development facilities and the U.S. Air Force Safety Center (AFSC). The purpose of the visit to AFSC was to visit the Human Factors Division. The mission of the AFSC Human Factors Division is to "support aviation, ground, space and weapons safety programs by applying human factors expertise to identify, analyze, and control human sources of unacceptable risk in Air Force operations" (http://www.afsc.af.mil/organizations/). The Human Factors Division conducts the human factors portion of USAF flight safety investigations into all air and ground based accidents and incidents, including all UAV systems operated by the USAF. The intent of the visit to the AFSC was to examine USAF flight safety data, and to explore possibilities for collaboration between DRDC Toronto and the AFSC on UAV human factors research. During the course of the tour, the following facilities were visited:

1. AFSC Data Simulation Center, and

2. AFSC Air Accident Training Center.

Unstructured interviews were conducted with the following individuals (names withheld):

1. Chief, Unmanned Aircraft Systems Safety Branch, and
2. Chief, Human Factors Division.

A.3.1 USAF Flight Safety Data

During the unstructured interviews, USAF flight safety data was discussed; these data are privileged under the USAF flight safety system. Consequently, access to the raw data was not provided. However, access to data that had already been analyzed was provided through printouts of graphs showing USAF mishap rates as related to cause factors. These data are summarized as follows:

Top manned aviation human factors cause factors (in descending order based on prevalence of cause factor for fiscal year 2008):

1. misperception of the environment;
2. publications and written guidance;
3. risk assessment choices;
4. channelized attention; and
5. skill-based errors.

Top MQ-1 Class A human factors cause factors (in descending order based on prevalence of cause factor for fiscal years 2004-2008):

1. organizational policies and written guidance;
2. man-machine interface;
3. attention management;
4. crew coordination; and

5. skill-based errors.

A.4 Conclusions

The findings reported in this annex represent the observations by two CFEME Air Accident Investigators during the visit to Creech AFB and Kirkland AFB. It is not the intent of this annex to draw conclusions based on these findings, merely to record what was observed. It is important to state that the personnel of Creech AFB are highly trained, professional warfighters performing a mission-critical job under demanding circumstances both from a human-systems integration viewpoint, and from a physiological and organizational viewpoint. The human factors challenges in the control of UAVs observed during these visits, while mostly anecdotal, are nevertheless reflected in the open literature relating to UAV operations. As such, these individuals are working hard, and largely succeeding, at completing their assigned missions despite the challenges they encounter on a day-to-day basis.

This page intentionally left blank.

Annex B Images of the MQ-1 Predator UAV

This annex contains four images of the MQ-1 Predator UAV gathered during the visit to Creech AFB. *Figure B-1* is a mock-up of a HUD screen in a MQ-1 aircraft, showing the image seen through the nose camera as well as all the aircraft instruments (overlaid on top of the camera image) available to the operator. A description of each element as seen on the screen can be found on the right-hand side of the figure. *Figure B-2* and *Figure B-3* are photos of the HUD, main screen, and variable text information screens of a portable GCS of a MQ-1 Predator. *Figure B-4* shows an exterior view of the front of a MQ-1 Predator, including the nose camera, boom, turn and slip indicator string and attitude indicator.

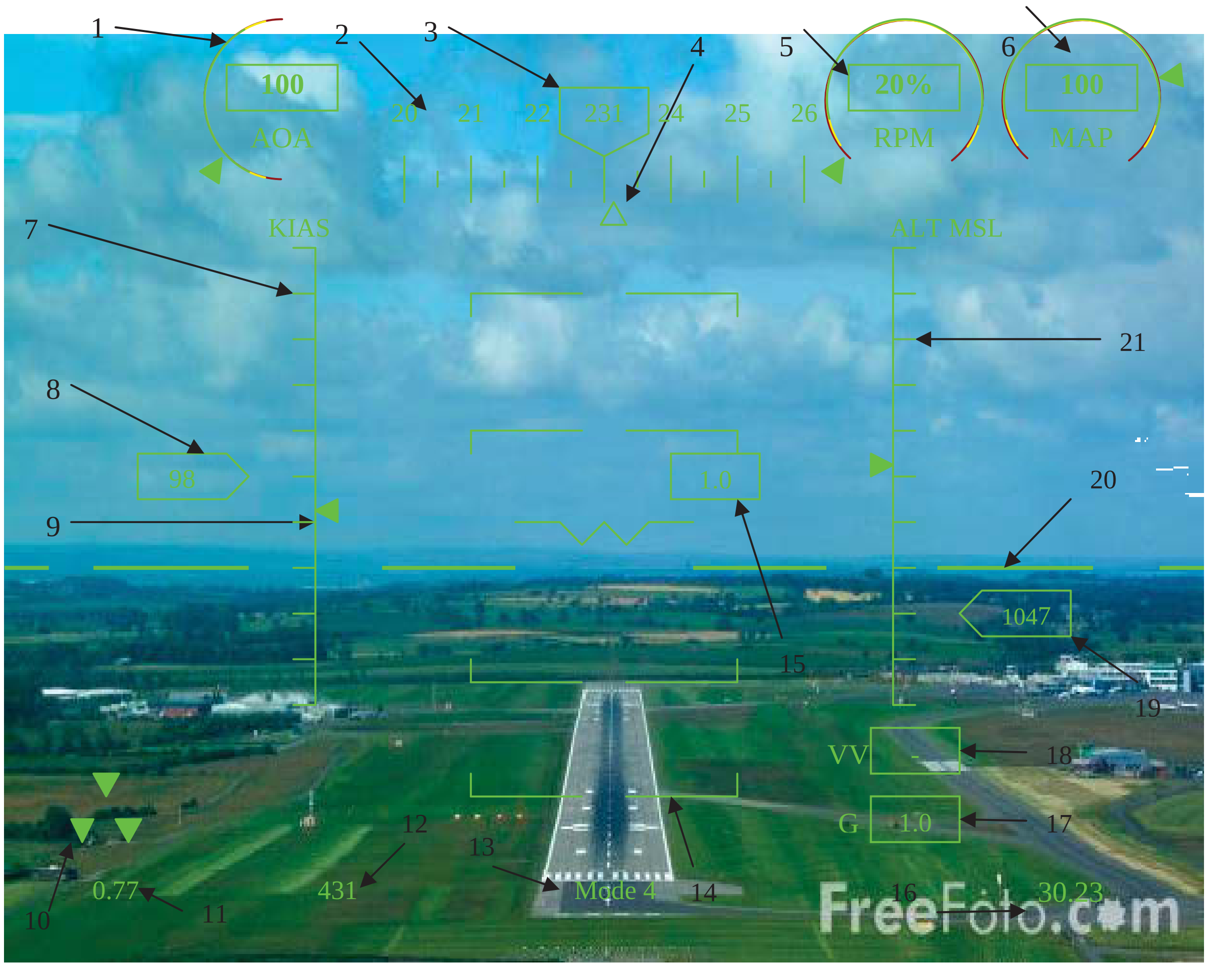
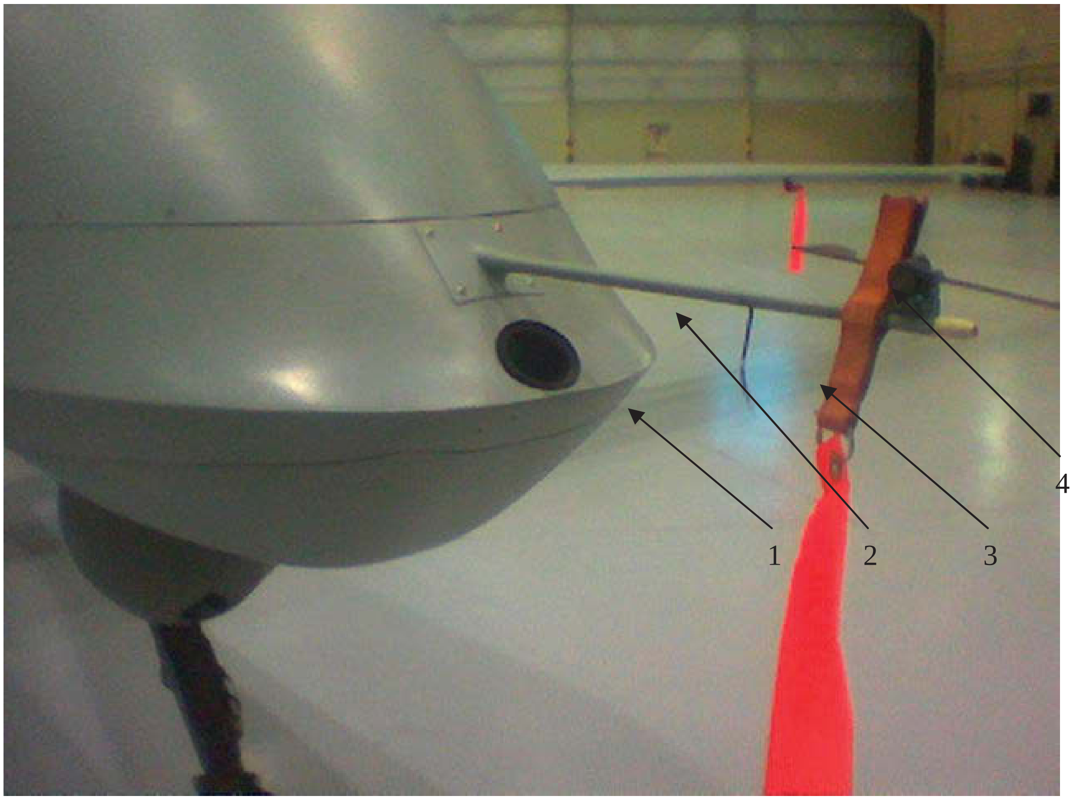


Figure B-1: Mock-up of MQ-1 Predator main screen and HUD.

KEY
1 Angle of Attack Indicator
2 Heading Scale
3 Current Heading
4 Waypoint Carrat
5 Engine RPM
6 Engine Manifold Pressure
7 Knots Indicated Airspeed Tape
8 Knots Indicated Airspeed
9 Unknown
10 Landing Gear Indicator
11 Unknown
12 Transponder Code
13 Transponder Mode
14 Pitch Ladder
15 Pitch Angle
16 Unknown
17 G meter
18 Vertical Velocity
19 Altitude
20 Artificial Horizon
21 Altitude Scale

Figure B-2: Portable MQ-1 Predator main screen and HUD.

Figure B-3: Portable MQ-1 Predator upper screen showing rendered variable text information screens.



KEY
1 Nose Camera
2 Boom
3 Turn and Slip Indicator
4 Altitude Indicator

Note that these items are visible in the nose camera view to aid in piloting the aircraft

Figure B-4: Nose of MQ-1 Predator.

Annex C UAV Accidents and Incidents Attributed to Human Error

This annex contains mishap investigation reports from the CF (Table C-1) and USAF (Table C-2). The mishap investigation reports for the CF were downloaded from the website of the Directorate of Flight Safety (http://www.airforce.forces.gc.ca/dfs-dsv/nr-sp/index-eng.asp?cat=262) on January 31, 2009. The Accident Investigation Board reports were downloaded from the website of the USAF (http://usaf.aib.law.af.mil/) on January 31, 2009.

Table C-1: UAV mishap data from Canadian Forces reports

#	Citation	Vehicle	Mission Phase	Materiel Cause Factors	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
1	CF report 2007/02/20	CU131004 Sperwer	Cruise	-Electrical short caused by the improper installation of the W34 holding bracket -Technical guide did not explicitly specify the correct orientation of the W34 holding bracket	-Maintenance personnel did not fully adhere to the procedures depicted in the technical guide -UAV crew did not receive HPMA Training	Deviations/routine Deviations/Transgression of orders – wing, base or unit
2	CF report 2008/08/06	CU161002 Sperwer	Take-off		-Modifications recommended as a result of previous occurrence were not carried out -Log entries were incomplete or missing from the launch record and the launcher maintenance record, not all maintenance actions were recorded in the maintenance log	Deviations/Routine deviations/Transgression of orders
3	CF report 2007/01/24	CU161014 Sperwer	Take-off	-System design fault allowed UAV to be launched while the Hybrid Navigational System was still on standby	-MC distracted by a radio call - MC failed to diligently follow checklist steps, checklist was not being directly referenced by the MC -Crew was using a modified and unapproved checklist due to perceived time pressures -Red thematic page warning that showed the Hybrid Navigational System was still in standby mode was available to crew but neither the AVO nor MC checked it prior to launch as this check was not an explicit checklist requirement	Errors/Skill-based errors/Inadequate technique/Omitted proper technique and/or Deviations/Routine deviations/Transgression of orders
4	CF report 2006/04/07	CU161007 Sperwer	Landing		-MC was unaware of the existence of an algorithm which must be used if UAV was to be recovered manually	Errors/Decision errors/Knowledge based or

#	Citation	Vehicle	Mission Phase	Materiel Cause Factors	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
					-SMM, Aircraft Operating Instructions, and SOP were either non-existent, or did not meet CF	information/Inadequate knowledge available
5	CF report 2005/11/18	CU161005 Sperwer	Landing	-Safety warnings were set to 200m AGL, which did not provide sufficient time to take alternative action when considering the factors of the mountainous terrain and UAV climb rate	standards -Crew's attention was channelized on approach and set-up for landing, leading to missed warnings -UAV flight crew had the habit of not responding to the warning tone when flight below the present 200m AGL sounded. The tone sounded so frequently during a flight that it became a nuisance and hence was disregarded -PO and his equipment were not being used effectively during the approach and recovery phase -The altitude screen, which was not selected, would have provided an additional level of visual cue that flight into terrain was imminent -The AVC did not receive formal 'hands on' training to actually operate the UAV -The simulation training provided by the OEM did not reflect the operational environmental parameters in Kabul, inexperience in mountainous terrain -No aircrew HPMA/CRM training had been provided to flight crew -OEM ability to provide instruction in English was minimal. At the time of this accident most documentation was in French only. -There were no SOPs and no SMM's for the operation of the UAV	Errors/Perception errors/Detection errors/Awareness error/Failure to attend to the visual cues detected
6	CF report 2005/11/17	CU161003 Sperwer	Landing	-Parachute package facility did not provide adequate climate controlled environment and lighting	-UAV project was rapidly introduced into service without the benefit of a comprehensive test and acceptance program -Lack of proper publications available to the TUAV Det and a lack of accurate performance data to the AETE flight test team	Errors/Decision error/Knowledge based or information error/Inadequate information available

#	Citation	Vehicle	Mission Phase	Materiel Cause Factors	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
					-Publications provided to the crews for instruction were not in accordance with the CF standards of bilingualism -Minimal or non-specific aircrew oriented CRM training was provided to members of the UAV operational flight team (AVC, AVO, PO, MP)	
7	CF report 2007/05/15	CU161009 Sperwer	Landing		-RAS personnel were unaware of the procedures associated with the proper handling of burnt carbon fibre -No independent check required to mitigate the risk associated with improper parachute installation -The OP Archer DARP did not prescribe handling procedure for hazardous materials, including burnt carbon fire -CU161 Sperwer Technical Guide did not provide explicit instructions pertaining to the pilot chute lanyard installation	Errors/Decision errors/Knowledge-based or information errors/Inadequate information available

Table C-2: UAV mishap data from United States Air Force reports

#	Citation	Vehicle	Mission Phase	Materiel Issue	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
1	U.S. report 2005/01/14	Predator MQ-1L	Cruise		-Incorrect procedures -Incorrect training, miscommunication and supervision problems	Unsafe act unknown
2	U.S. report 2006/03/20	Predator MQ-1L	Cruise		-Mishap pilot used poor judgment when he turned off SAS pitch and roll axes -Confusion over flight characteristics of the UAV, led to erroneous conclusion that there was a control problem	Errors/Perception errors/Understanding error/Failure to understand visual cues
3	U.S. report	Predator	Cruise, in	-Software anomaly	-Mishap pilot disengaged autopilot (pre-program	Errors/Skill-based

#	Citation	Vehicle	Mission Phase	Materiel Issue	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
	2003/12/11	RQ-1L	icing conditions	caused high pitch angle setting without pilot's awareness -Intermittent link connectivity with mishap RPA due to abrupt pitch stick inputs	flight and airspeed hold) due to mishap crew icing analysis -Abrupt pitch inputs were made by the mishap pilot during a nose high unusual attitude after disengaging autopilot	errors/Poor-inappropriate technique
4	U.S. report 2001/03/30	Predator RQ-1L	Cruise, in icing conditions		-Failure to immediately execute critical checklist steps for pitot static icing -Non-use of the pitot static heating system	Unsafe act unknown
5	U.S. report 2000/09/14	Predator RQ-1L	Cruise	-Mishap in the basic design of the Predator control system, menu system in the GCS allowed a crew member to place the aircraft in hazardous conditions without any warning or verification that the keystroke made was the correct or intended entry -Primary Control Module default values for weight and lost link altitude created a condition that led to aircraft impact	-Mishap pilot activated of the "Program AV EEPROM" menu option during flight which dumped the RAM memory in the UAV's Primary Control Module, clearing the pre-programmed data, including weight, frequencies, tail number and IFF squawk -As a result of habit developed over time and a sense of being rushed, the pilot failed to verify the menu page and options to ensure he was hitting the correct key before entering a command	Errors/Skill-based error/Poor-inappropriate technique
6	U.S. report 2002/01/22	Predator RQ-1L	RSO/Transf-er of control between		-Mishap's crew failed to accomplish checklist items in proper order	Errors/Skill-based errors/Inadequate technique/Omitted proper technique

#	Citation	Vehicle	Mission Phase	Materiel Issue	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
			GCSs			
7	U.S. report 2002/10/25	Predator RQ-1L	Descent, changing altitudes in mountains		-Crew was inattentive to attitude -Loss of SA due to fixation on landing gear checklist procedures, distraction with antenna and transmitter configuration management -Incorrect analysis of lost downlink video and the untimely application of emergency actions procedures for "Total Downlink Failure Below 2,000 Feet AGL"	Errors/Perception errors/Detection errors/Inaccurate detection of visual cues
8	U.S. report 2004/01/14	Predator MQ-1L	Landing		-Late-executed go around from a poorly flown approach -Aircraft hit tail first due to the student pilot setting too high of a nose pitch for the go around	Errors/Skill-based error/Poor-inappropriate technique
9	U.S. report 2007/03/26	Predator MQ-1B	Landing	-Lack of visual cues and cues to provide body position/movement within the GCS -Unique flight control logic and lack of pilot feedback -Lack of cues is part of an inherent design flaw making the system conducive to the types of perceptual errors that occurred during the mishap sequence	-Mishap pilot misjudged the RPA height above touchdown and confused the initial bounce with a normal aircraft response to his flare inputs	Errors/Perception errors/Detection errors/Failure to understand the visual cues
10	U.S. report 2004/10/13	Predator MQ-1L	Landing		-Student pilot's control inputs caused a series of pilot induced oscillations and the instructor pilot's failure to take appropriate corrective action	Errors/Skill-based errors/Inadequate technique/Poor-

#	Citation	Vehicle	Mission Phase	Materiel Issue	Personnel Cause Factors (Unsafe Acts or Conditions, Preconditions for Unsafe Acts, Supervision, and Organizational Influences)	CF-HFACS Unsafe Acts
					-Aeronautical System Inc.'s failed to train and prepare their student pilots for pilot induced oscillations	inappropriate technique
11	U.S. report 2005/10/21	Predator MQ-9A	Landing		-Mishap instructor pilot failed to control aircraft glidepath, aimpoint, and airspeed on short final, and executed a go-around too late -Breakdown in CRM -Inadequate supervision	Errors/Skill-based errors/Inadequate technique/Poor-inappropriate technique
12	U.S. report 2006/08/03	Predator MQ-1B	Landing		-Mishap instructor pilot turned his head away from the confirmatory message on the HUD while talking to someone else in the GCS -Plot inadvertently pressed the "kill engine" switch instead of retracting landing gear	Errors/Skill-based errors/Inadequate technique/Poor-inappropriate technique
13	U.S. report 2004/11/24	Predator MQ-1L	Landing, emergency		-Failed to execute landing checklist -Pilot's mishandled the aircraft malfunction -Training, flight discipline and supervision issues contributed to the pilot error	Unsafe act unknown

This page intentionally left blank.

Annex D Trip Report to Observe CU-170 Heron UAV at CFB Suffield / MDA

D.1 Introduction

D.1.1 Background

Unmanned aerial vehicles (UAVs) have become a vital tool for intelligence, reconnaissance and surveillance missions for the Canadian Forces (CF). While there are many benefits of using UAVs over manned aircrafts, UAV mishaps occur at the much greater rate than manned aircrafts. Many of these mishaps are attributed human factors related issues (Herz, 2008; Manning et al., 2004; McCarley & Wickens, 2005; Tvaryanas et al., 2005; Williams, 2004).

To address human factors issues when operating UAVs, an Applied Research Program (ARP) entitled "Multimodal Displays for Controlling Uninhabited Aerial Vehicles" was started at Defence Research and Development Canada (DRDC) – Toronto in 2009 to examine methods to improve operator performance by using a multimodal interface. This ARP supports the JUSTAS (Joint Unmanned Surveillance Target Acquisition System) program which is a Canadian Department of National Defence (DND) program aimed at procuring future UAVs for the Canadian Forces (CF).

Currently, the CF does not own MALE UAVs but rather leases the Heron UAV which is used in theatre in Afghanistan. The present trip report outlines findings of a site visit to CFB Suffield to observe and document both the technological capabilities of the Heron UAV and the human factors of operating the Heron UAV.

D.1.2 Purpose and Scope

The purpose of the site visit to CFB Suffield was to gather knowledge about the CF's current UAV capabilities and to gain a stronger understanding of UAV technologies specifically related to the Heron UAV. In particular, we wanted to observe and gather knowledge on automated take-off and landing (ATOL), which is a relatively new feature to UAVs. In addition we wanted to examine the human-machine interface and the automation capabilities of the Heron.

D.2 CFB Suffield / MDA Heron UAV Site

MacDonald, Dettwiler and Associates (MDA) (Richmond, British Columbia) has been contracted by the CF to oversee the training and operations of the Heron UAV. The MDA site at CFB Suffield is located in the airfield. Temporary hangers and trailers have been set up to accommodate the UAV training. The site houses one ground control station (GCS) and one simulator for training. The training trailer houses a Heron GCS simulator, the training classes and the study areas (*Figure D-1*).

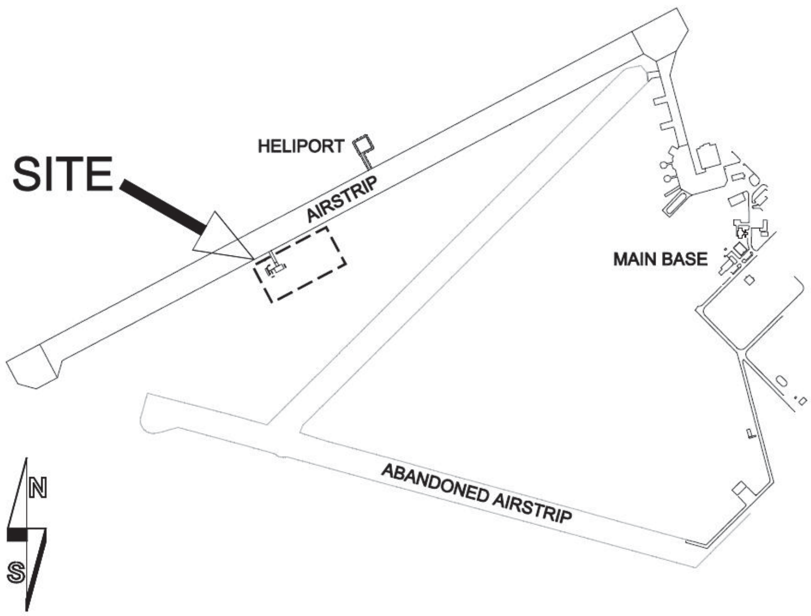


Figure D-1: Location of MDA site at CFB Suffield.

D.3 CU-170 Heron UAV

The Heron UAV is a medium-altitude, long-endurance (MALE) UAV developed by Israel Aerospace Industries Malat (Ben-Gurion Airport, Israel). An air vehicle operator (AVO) flies the Heron from the (GCS) which communicates to the Heron through a ground data terminal (GDT). The range of communications is 250km but can extend using satellite communications. Using the GCS controls, the AVO can fly the UAV under different levels of automation. Normally, mission planners pre-program waypoints and the AVO directs the Heron to automatically fly along its programmed route. The AVO can modify or add new waypoints during the mission and if necessary, the AVO can take control of the Heron and fly it manually using a separate control unit (see Section D.5). The AVO can also command the Heron to fly in holding patterns or direct the plane to fly in the direction of the active camera. The active camera can refer to the panoramic camera or one of the payload sensors. Figure D-2 and Table D-1 provide the specifications for the Heron.

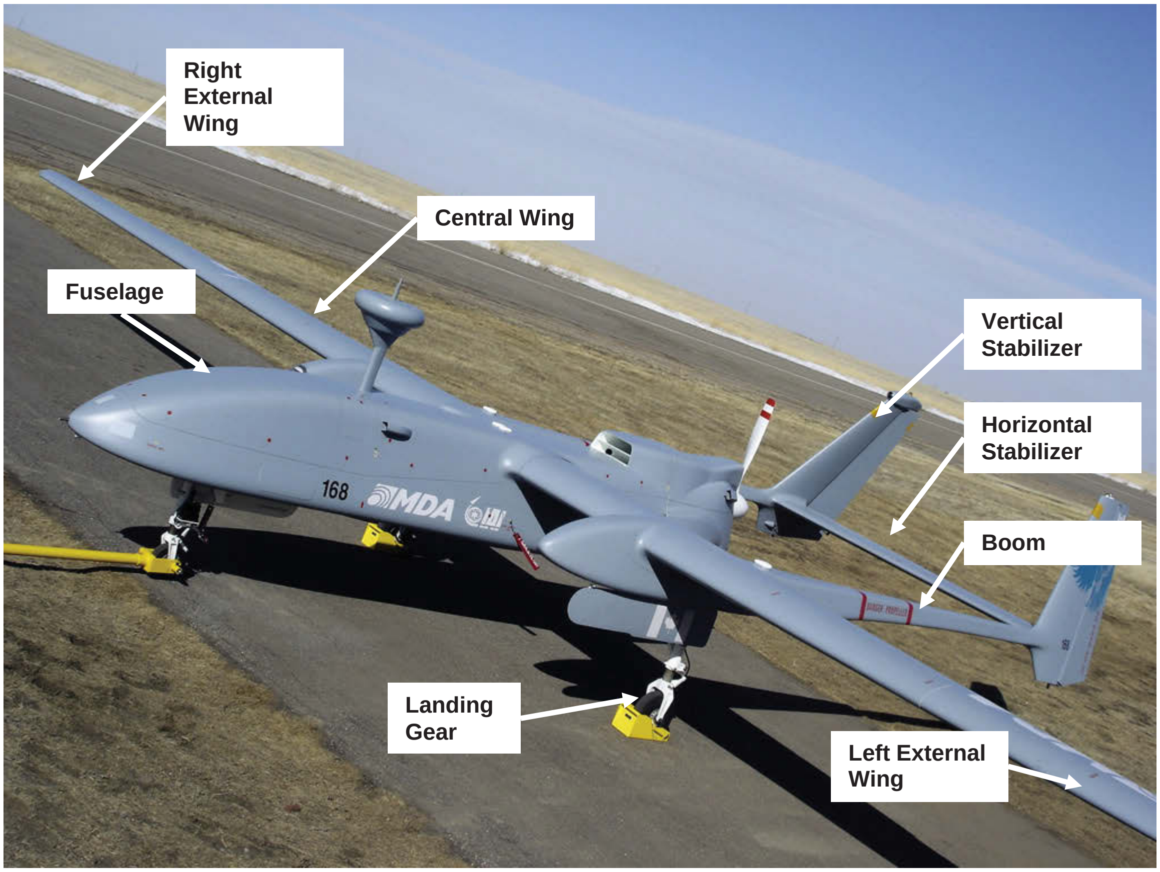


Figure D-2: CU-170 Heron UAV.

Table D-1: Specifications of the Heron UAV.

Wing Span	16.60 m
Engine Power	100 / 115 hp
Maximum Take-off Weight	1150 kg
Total Fuel Capacity	620 litres
Operational Ceiling	27,000 ft
Endurance Time	24 hrs
Payload Weight	250 kg
Maximum Airspeed	110 kts

The payload operator (PO) controls the sensor cameras. The Mission Optronic Stabilize Payload (MOSP) unit houses the sensors. The MOSP has a charge-coupled device (CCD) camera for daytime imaging, an infrared (IR) camera for night time imaging, an electro-optical (EO) sensor, and a laser pointer.

The Heron is susceptible to various meteorological / atmospheric conditions. Wind shear and turbulence can alter the UAV's velocity, altitude, and lift. As such, AVOs are instructed to keep 25km away from known problems. The Heron is also susceptible to ice hazards, as frost can decrease lift. Rime ice (which occurs in clouds) can reduce velocity. Clear ice (which also develops in clouds) can affect steering and produce significant weight on the AV. To prevent icing, the AVO is instructed to stay away from clouds, not to fly in rain or humid areas where temperatures drop below 0º C. Additionally, the UAV should not take-off when there is any ice on the UAV or runway. There is no de-icing capability on the UAV. Lightning can also affect electrical systems, stall the engine and create holes in the UAV structure. AVOs are instructed to keep 25 km away from storm clouds and avoid flying over them.

D.4 Air Vehicle Operators and Payload Operators

All student AVOs had previous flying experience in manned aircrafts and/or had experience in other aviation trades (e.g., navigator). The AVOs are all given initial flight theory training by IAI in Israel. The theory course can range from 2 – 5 weeks depending on the schedule. The students are sent to the site at CFB Suffield for six weeks (although much of the time is downtime waiting for optimal flight conditions). During this period, they conduct 15 basic flight lessons and 10 emergency lessons on the simulator. They also conduct 3 actual basic flights, 4 automated take-off and landing, and 8 mission support flights with a payload operator (PO). After this basic training, the AVOs conduct exercises (the group that was observed during this trip was sent to California) before being deployed to Afghanistan for 3 weeks. In Afghanistan, they will initially shadow more experienced AVOs and their first few flights will be monitored by an experienced AVO.

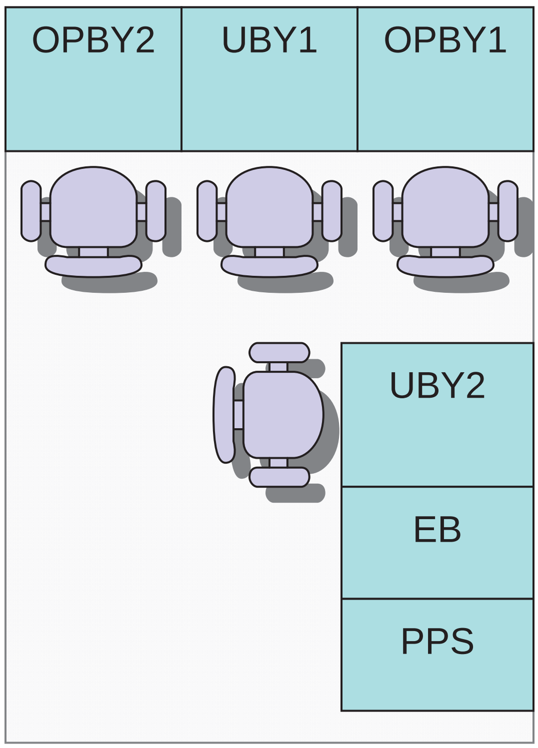
While the tasks for the AVO and PO may differ slightly from site to site, the main tasks for each operator are listed below in *Table D-2*.

Table D-2: Air vehicle operator and payload operator operational tasks.

	AVO	**PO**
Tasks	Mission Planning	Carrying Out Pre-flight Checks of GCS
	Briefing	Instructing the AVO Regarding Flight Navigation to Support Mission
	Performing Communications	Selecting and Controlling Payload Sensors
	Conducting Pre-flight Checks of the UAV and GCS	Identifying and tracking targets
	Performing Engine Start Up	Enhancing Real-time Video of Images
	Carrying Out Taxi Procedures	
	Carrying Out Take-off Procedures	
	Navigating the UAV	
	Modifying Mission Goals and Controls	
	Monitoring UAV, GCS and Data Links	
	Landing the UAV	
	Debriefing the UAV crew	

D.5 Ground Control Station

The GCS is housed in a container and seats up to four people. *Figure D-3* shows the standard configuration for the GCS and *Figure D-4* shows the actual interior of the GCS. While the two operator bays (OPBYs) are identical, the AVO normally occupies OPBY1 and the PO occupies OPBY2. If malfunctions occur, OPBY1 becomes the default AVO station. User bay (UBY) 1 and UBY2 are either non-operational or occupied by instructors, other payload operators, or commanding officers. UBY1 allows the operator to use specialized payloads such as synthetic aperture radar (SAR). UBY2 allows the operator to do additional monitoring of the other stations.



KEY
OPBY (Operator Bay)
UBY (User Bay)
EB (Equipment Bay)
PPS (Protected Power Supply)

Figure D-3: Block diagram of the GCS for the CU-170 Heron.

Figure D-4: Interior of the Heron UAV GCS.

Working in the GCS was challenging. The space was very tight[1]. There was little room to move and some operators had to duck their heads while walking in the GCS. The ambient light is low (not measured) if the door is closed. A heating, ventilating, and air conditioning (HVAC) system controls the temperature of the GCS. On the day of the site visit, the temperature was 22º C, although one operator noted that the GCS can get warm. When operating, the fans in the GCS are constantly running increasing the ambient noise level, thus requiring operators to raise their voices during face-to-face communications.

Figure D-5 presents the layout for the operator bay's display and controls. . The top display uses a 19" monitor that shows a map display, the data links, and the warning panels. The lower 15" display shows the camera view and the UAV controls. A communications panel is to the right of the lower 15" display. The AVO navigates the controls using a trackball, and the PO controls the payload cameras using a joystick (*Figure D-6*). A keyboard and a set of hot keys are used for keyed inputs. An external stick control box is used to manipulate some UAV controls such as engine start-up and flaps. This controller is very similar to the controller for a small remotely controlled plane and can be used to manually fly the aircraft.

[1] Estimated dimensions of the GCS are 9 (l) x 5 (w) x 5'10 (h).

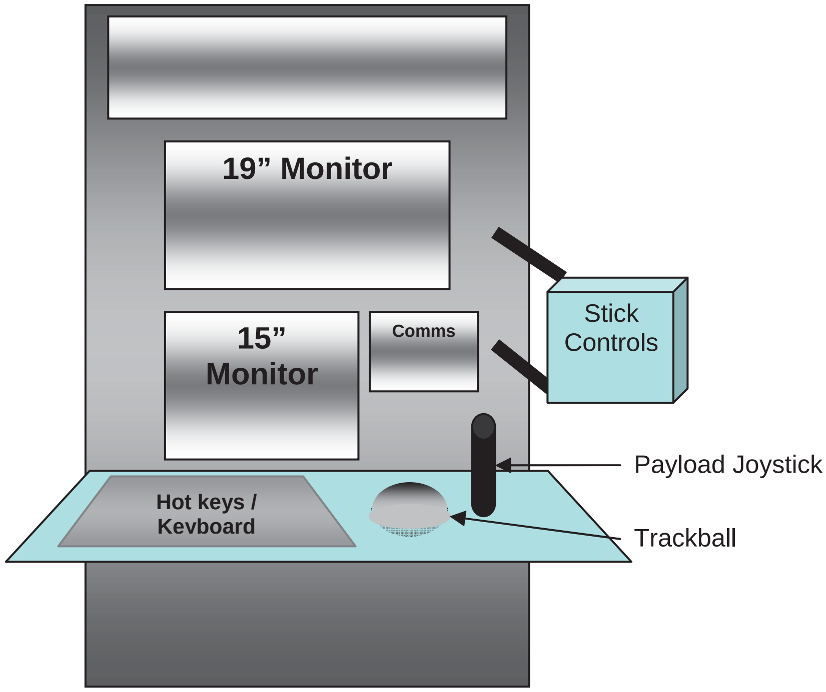


Figure D-5: General layout of the operator bay in the Heron UAV GCS.

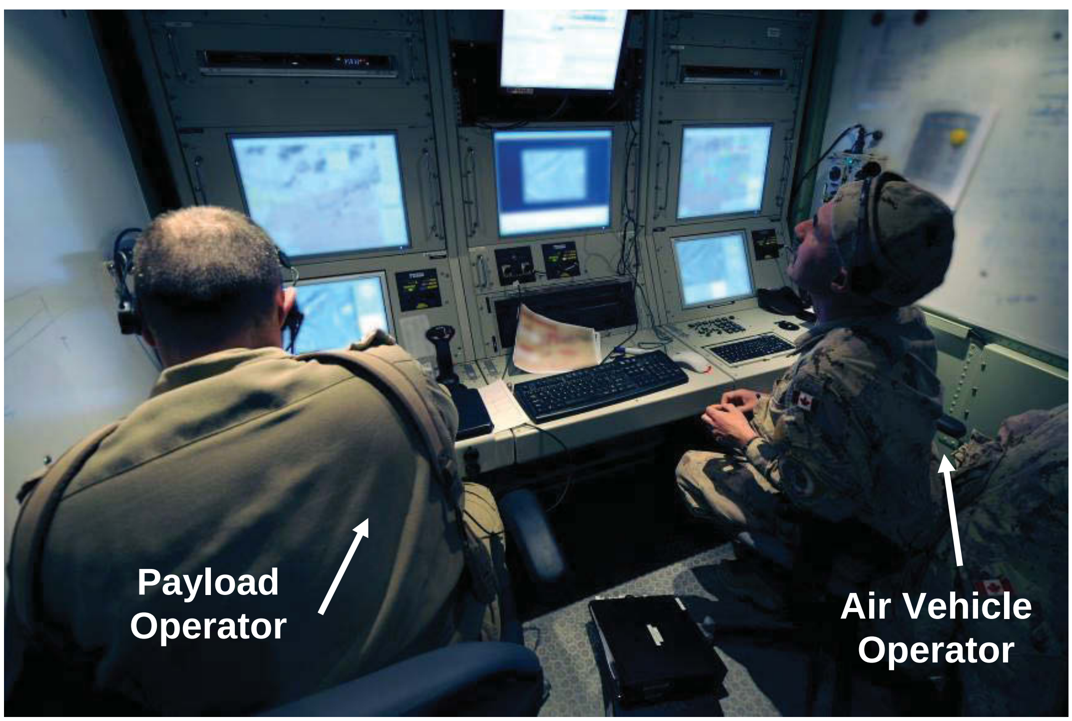


Figure D-6: Crew operating the Heron UAV from the GCS.

The AVO uses two primary displays to fly the Heron. The basic layout of the top display is illustrated in

Figure D-7. This display shows the position of the UAV on a map. Overlaid on the map are the waypoints, the current travelling direction of the UAV, the wind speed and wind direction, and the launch and recovery site. To the right of the map, a display shows the downlink and uplink signal strength. Two warning panels, one for UAV warnings and the second for GCS warnings, are below the signal strength indicators. If a warning appears in either of these panels, a master warning alert also appears in the lower display. In addition, the primary menus to control the aircraft are located on this top screen. For example, the AVO can select a change in the waypoint by selecting an icon from the toolbar. A popup box would appear that would allow the AVO to key in the new waypoint settings.

The lower display shows the current active camera view, the UAV flight instruments, and the master caution (

Figure D-8. The primary camera for the AVO is the panoramic (PANO) camera. This camera is located on the right rear vertical stabilizer; thus, when the AVO uses this camera, he/she can see the entire rear of the Heron flying over the current terrain. Overlaying this camera view are two instruments readings, heading and ground speed. If desired, the AVO could switch to other payload sensors.

To the top-right of the camera view are a number of flight instruments:

- Airspeed Indicator
- Altimeter
- Heading Indicator
- Turn Indicator
- Bearing and Depression Angle Indicator
- Glideslope Indicator

Beneath the flight instruments were engine relevant indicators such as power, fuel level and fuel flow, oil pressure and oil temperature, and engine temperature. This area also has indicators for the landing gear, landing lights, and brakes.

Immediately underneath the camera view window are two panels showing status updates, one for the UAV and another for the GCS. These two panels display only status information and are not redundant with warning panels.

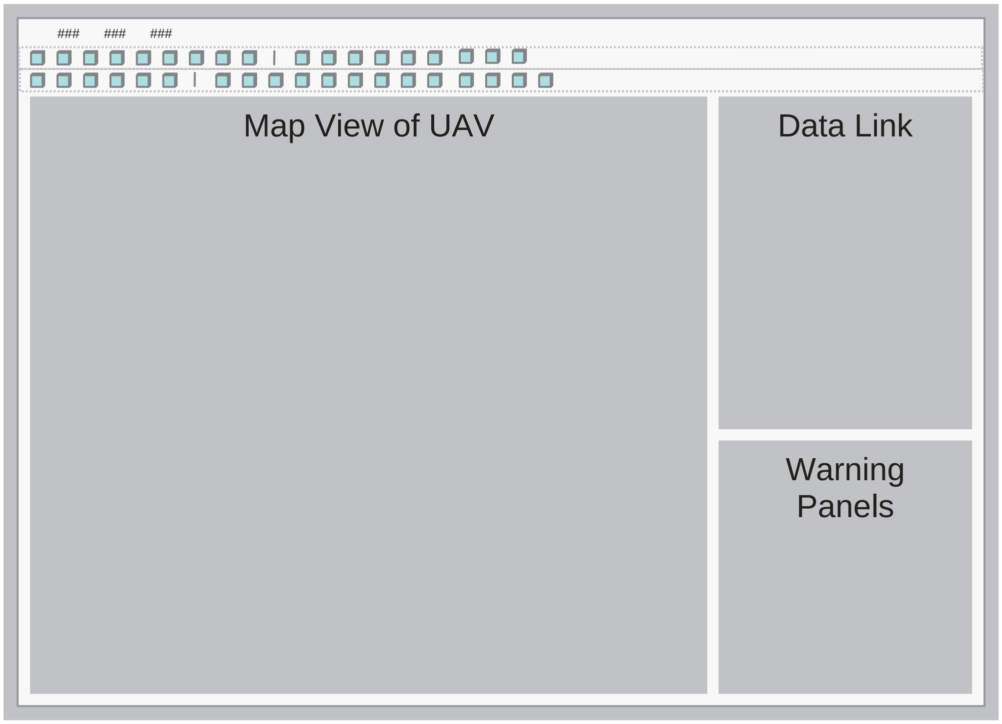


Figure D-7: Layout of the interface shown on the 19” top screen of the Heron UAV GCS.

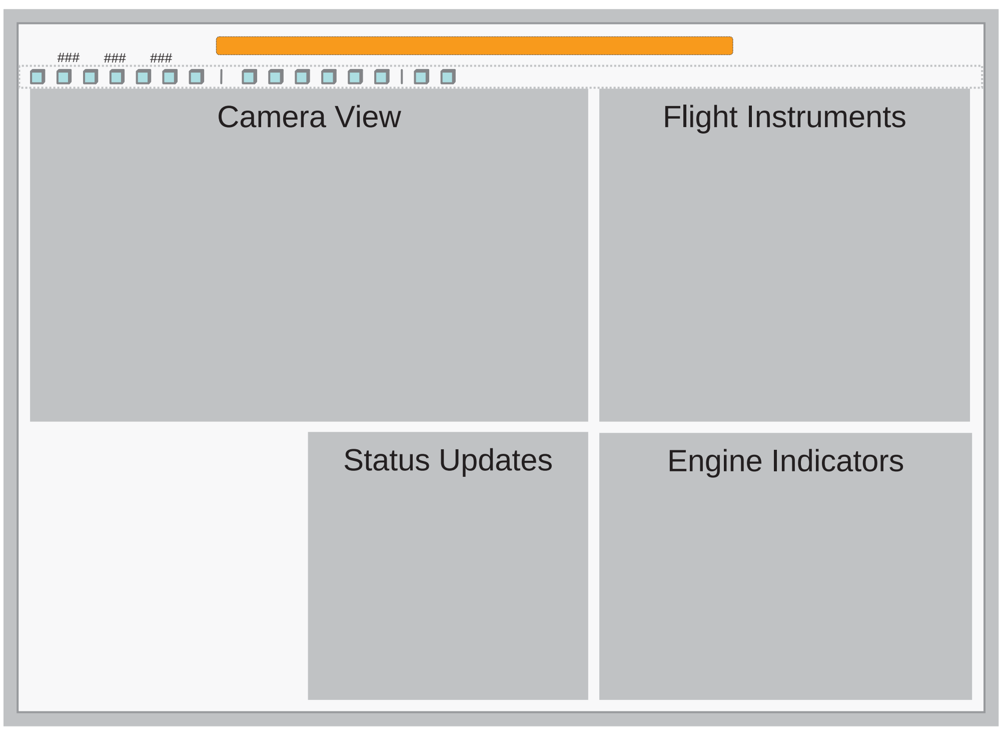


Figure D-8: Layout of the interface shown on the 15” bottom screen of the Heron UAV GCS.

D.6 Automated Take-Off and Landing

The Heron is capable of automated take-off and landing (ATOL). That is, the Heron takes off and lands on a runway like a fixed wing manned aircraft, but under the control of automation. The AVO's task is to set up the UAV's take-off procedure and to prepare the UAV for an approach to land. Once the take-off and landing has been initiated, the AVO monitors the variables to ensure that the execution of the ATOL is safe. If there are any safety issues, the AVO can choose to abort the ATOL.

Normally, ATOLs are conducted using DGPS (differential GPS) using a standard landing checklist procedure. The AVO first directs the UAV to the initial landing waypoint. As the UAV approaches this waypoint, the AVO conducts various checks prior to the approach. For example, the AVO must inform ATC that they are landing, ensure that there is a clear runway for use, check that the DGPS is working, lower the landing gear, extend the flaps to the landing position, and ensure that all engine and flight indicators are normal. If the conditions for landing are not met, the automation will not allow the AVO to initiate the landing.

When landing, the glideslope indicator replaces the heading indicator. The UAV will follow the pre-programmed glideslope and speed and adjust for any small deviations. If there are winds, the algorithms in the autoland system are designed to bank and crab the UAV to adjust for the winds automatically. The AVO monitors the UAV's path relative to the desired glideslope, the air and ground speed, and its altitude and rate of descent.

During landing, if a significant problem occurs (e.g., a strong wind) prior to the decision height (approximately 47 feet), the UAV will automatically abort the landing. The AVO can also initiate a manual abort prior to the decision height by pressing an abort button on the GCS keypad. If an abort is initiated, the UAV will fly to a wave off point where it will run a hold pattern. After the decision height, the UAV will try to land, despite all warnings.

When the UAV is approximately 300 feet from touch down, another altitude indicator is activated on the camera view window. The UAV will initiate a flare at 21 feet, decrab at 10 feet and deroll at 9 feet from the touchdown point.

If an emergency occurs during flight, AVOs use a separate emergency checklist and a landing procedure. The checklist will depend on the type of emergency. Generally, the AVO determines if the UAV can reach home base or if an emergency recovery site will need to be established. The AVO might have to shed power or perform manoeuvres to lose altitude (e.g., perform repeated banking manoeuvres or lower the flaps). An emergency landing mode can be used. Under this mode, the automatic abort is deactivated and only the AVO can abort the landing.

In the case that the DGPS fails, the Heron has an additional automatic landing method called remote autoland positioning system (RAPS). RAPS uses a laser tracker to determine the position of the UAV relative to the touchdown point. If a data link loss occurs during flight, the Heron has an automatic Return to Base (RTB) feature that will send the Heron back to its home base.

Finally, if all else fails, the AVOs can land the Heron manually, however, this is strongly discouraged and is an unlikely scenario.

D.7 Conclusions

The Heron UAV provides the CF with significant advantages over Canada’s previous UAV, the Sperwer. The Heron allows for longer flight times and can fly at higher altitudes. The payload capabilities of the Heron also provide the CF with additional intelligence, surveillance and reconnaissance capabilities. In addition, the ATOL system is expected to also reduce the number of UAV mishaps.

This report describes the observations and discussions provided during a site visit to MDA’s Heron training facility located at CFB Suffield. The report describes an initial and relatively superficial overview of the Heron capabilities and some of its limitations. We describe the air vehicle itself, the GCS, and the tasks of the operators. The views are anecdotal and are intended to serve the knowledge acquisition phase of the larger project.

This page intentionally left blank.

List of abbreviations

13QH(Command)	Applied Research Project on Multimodal Displays for Controlling UAVs under Partner Group 13QH(Command)
ACSOs	Air Combat Systems Operators
AEW	Air Expeditionary Wing
AFB	Air Force Base
AFSC	Air Force Safety Center
AIB	Accident Investigation Board
ALIX	Atlantic Littoral ISR (Intelligence, Surveillance, and Reconnaissance) Experiment
AOI	Areas of Interest
ARP	Applied Research Project
ATC	Air Traffic Control
ATOL	Automated Take-Off and Landing
AVO	Air Vehicle Operator
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CF	Canadian Forces
CFB	Canadian Forces Base
CFEC	CF Experimentation Centre
CFEME	Canadian Forces Environmental Medicine Establishment
CONUS	Continental U.S.
CP140	Canadian Maritime Patrol Aircraft
CRM	Crew Resource Management
CTA	Cognitive Task Analysis
CU-161	Sperwer UAV
CU-170	Heron UAV
DGPS	Differential GPS
DRDC	Defence Research and Development Canada
EB	Equipment Bay
EO	Electro-Optical

ERAU	Embry-Riddle Aeronautical University
FOD	Foreign Object Damage
FY	Fiscal Year
GCS	Ground Control Station
GDT	Ground Data Terminal
HCI	Human-Computer Interaction
HFACS	Human Factors Analysis and Classification System
HMI	Human-Machine Interface
HPMA	Human Performance in Military Aviation
HUD	Heads Up Display
HVAC	Heating, Ventilating, and Air Conditioning
IAI	Intelligent Adaptive Interface
IPME	Integrated Performance Modelling Environment
IR	Infrared
JSI	Job Similarity Index
JUSTAS	Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System
LRE	Launch and Recovery Element
MALE UAV	Medium-Altitude, Long-Endurance Uninhabited Aerial Vehicle
MC	Mission Commander
MCE	Main Control Element
MDA	MacDonald, Dettwiler and Associates
mIRC	M Internet Relay Chat
MOB	Main Operating Base
MOC	Military Occupation Classification
MOSID	Military Occupational Structure Identification Database
MOSP	Mission Optronic Stabilize Payload
MQ-1	Predator UAV
MQ-9	Reaper UAV
NASA-TLX	National Aeronautics and Space Administration - Task Load Index
NATO	North Atlantic Treaty Organization
OMI	Operator Machine Interface
OPBY	Operator Bay

PANO	Panoramic Camera
PO	Payload Operator
PPS	Protected Power Supply
RAPS	Remote Autoland Positioning System
RAS	Recovery and Salvage
RC-135	Surveillance Aircraft
ROTC	Reserve Officer Training Candidate
RPA	Remotely Piloted Aircraft
RPM	Revolutions Per Minute
RQ-1	Predator UAV
RQ-2	Predator UAV
RQ-5 Hunter	Hunter UAV
RQ-7 Shadow	Shadow UAV
RTB	Return to Base
SA	Situation Awareness
SAR	Synthetic Aperture Radar
STANAG	Standardization Agreement
TUAV	Tactical UAV
UAV	Uninhabited Aerial Vehicle
UBY	User Bay
UK	United Kingdom
US	United States
USAF	United States Air Force
VIT	Variable Information Terminal

This page intentionally left blank.

DOCUMENT CONTROL DATA
(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (The name and address of the organization preparing the document, Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's document, or tasking agency, are entered in section 8.)

Publishing: DRDC Toronto
Performing: DRDC Toronto
Monitoring:
Contracting:

2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.)

UNCLASSIFIED

3. TITLE (The complete document title as indicated on the title page. Its classification is indicated by the appropriate abbreviation (S, C, R, or U) in parenthesis at the end of the title)

Human Factors Issues for Controlling Uninhabited Aerial Vehicles: Preliminary Findings in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System Project (U)
(U)

4. AUTHORS (First name, middle initial and last name. If military, show rank, e.g. Maj. John E. Doe.)

G. Robert Arrabito; Geoffrey Ho; Annie Lambert; Mark Rutley; Jocelyn Keillor; Allison Chiu; Heidi Au; Ming Hou

5. DATE OF PUBLICATION (Month and year of publication of document.)

August 2010

6a NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)

117

6b. NO. OF REFS (Total cited in document.)

126

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Report

8. SPONSORING ACTIVITY (The names of the department project office or laboratory sponsoring the research and development − include address.)

Sponsoring:
Tasking:

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant under which the document was written. Please specify whether project or grant.)

9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)

10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document)

DRDC Toronto TR 2009−043

10b. OTHER DOCUMENT NO(s). (Any other numbers under which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (Any limitations on the dissemination of the document, other than those imposed by security classification.)

Unlimited distribution

12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11), However, when further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited announcement

DOCUMENT CONTROL DATA

(Security classification of the title, body of abstract and indexing annotation must be entered when the overall document is classified)

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

(U) The Directorate Technical Airworthiness and Engineering Support 6 tasked Defence Research and Development Canada (DRDC) – Toronto to provide a preliminary summary of human factors issues related to the control of uninhabited aerial vehicles (UAVs) in support of the Canadian Forces Joint Unmanned Aerial Vehicle Surveillance Target Acquisition System (JUSTAS) project. This was carried out by performing a literature review, and consulting with subject matter experts. The human factors topics discussed are organizational influences, operator influences, and human−system integration issues. The key findings were: (1) human factors play a major role in UAV mishaps, (2) operator vigilance is required in automated UAV control, (3) recent increases in long−endurance UAV operations have necessitated shift work schedules to man the GCS around−the−clock that has caused UAV operators to experience fatigue leading to serious implications on health and performance, (4) a ground control station interface that supports a multimodal display (i.e., an interface that uses visual, auditory, and tactile cues) can enhance operator performance, and, (5) prior pilot experience may not be a mandatory criterion for selecting individuals for operating the Predator UAV. This report concludes by proposing short− and long−term recommendations for defining future requirements in support of the JUSTAS project.

(U)

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) uninhabited aerial vehicles; human factors; operator performance; ground control station interface; accidents and incidents

Defence R&D Canada

Canada's Leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca